



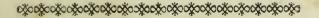
Henry Gee Burnard 1839.)











## CHEMICAL ESSAYS.

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### CHEMICAL ESSAYS.

#### BY

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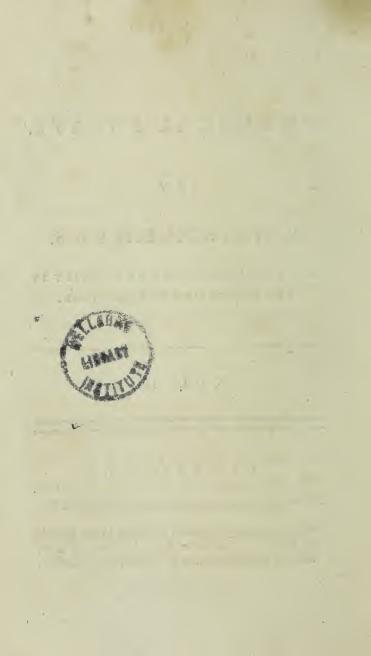
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ADVER-



### ADVERTISEMENT.

Have every reason to be satisfied with the reception which has been given to my two former volumes of Chemical Effays. My defign was to have published two others on the same plan, but this is the last for which I shall ever presume to intreat the indulgence of the public. I perceived, as I proceeded in the work, that two additional volumes would not contain half the materials which I had collected; and despairing of ever finding leifure to arrange the whole, I have contented myself with

with putting into this volume, what gave me the least trouble in revising. For feveral months I have had great reason to believe, that an attention to health ought to occupy that leifure, which I have hitherto bestowed on the study of Chemistry. It is a fludy of fo bewitching a kind, that few persons can cultivate it with moderation, or fail of feeling symptoms of that disorder, which Beccher in speaking of himself, describes in the following terms, \* - cui nec Aulæ Splendor, nec æconomiæ ratio, nec famæ integritas, nec sanitatis vigor, quicquam præ carbonibus, venenis, fuligine, follibus, et furnis valere potest.

Phy. Subter. Præ.



## ESSAY I.

# Of Bitumens, and Charcoal.

THE analyses of pitcoal and of different woods, mentioned in the last Essay, may serve as instances of the products obtainable by distillation from bituminous and vegetable substances in general. They all of them yield water impregnated with an acid, and often also with a volatile alkaline salt, air, oils of different colours, weights, and consistences, and a black coaly residuum. The bitumens generally taken notice vol. III. A of

of by writers on Natural History are, with respect to their consistence, either as fluid as oil, or as thick and tenacious as tar, or quite folid. The fluid bitumens are two, Naptha, and Petroleum, or rock-oil. These are oils which differ from each other in colour and confistence, and some other properties; the naptha is pale, light, and very inflammable; the petroleum is yellow, brown, or blackish, heavier and less inflammable than naptha: its difference from naptha is attributed to its containing a greater quantity of acid in its composition. Both these oils are found in many parts of the globe, either floating on fpring water, or dripping from the crevices of rocks. Mineral pitch is a bitumen which differs from petroleum in being thicker, heavier,

and more glutinous; it was formerly found in the environs of Babylon, and constituted, according to Vitruvius, when mixed with lime, the cement which was used in building the walls of that city. At present it is met with in several parts of Europe, and in America, where it drips from rocks, and is called by us Barbadoes tar: it has a very offensive smell, and great tenacity, and is called by the inhabitants of Auvergne, in France, where it exudes from the earth, and sticks to the feet, devils' dung. The asphaltum, or jews-pitch, is a bitumen much resembling mine. ral pitch; it is thrown up in a liquid form from the bottom of the lake where Sodom and Gomorrah stood, otherwise called the Dead sea, or the lake Asphaltes, from a Greek word denoting A 2

denoting a bitumen. This lake in the time of Esdras yielded bitumen - remember what I did to Sodom and Gomorrah, whose land lieth in clods of pitch\*. -The bitumen, floating upon the furface of the falt water, is condensed by the heat of the sun into a folid form, and is gathered by the Arabs on the shore where it is thrown. It is said to be the fame substance which the Egyptians used in embalming their mummies, and it was called by them mumia mineralis +. This bitumen has been found in many places of Asia and Europe, as well as on the shores of the Dead sea; all that we meet with in the shops, is either an artificial composition, or an European asphaltum, the Eastern ones being seldom brought into Europe, but used

<sup>\*</sup> Efd. B. 2. c. 2.

<sup>+</sup> Hasselquist's Voy. p. 285.

used by the natives either as pitch for their ships, or as an ingredient in varnishing, or dying wool.

There is a very curious experiment which illustrates the relation which these four bitumens bear to each other. The most transparent oil of turpentine, refembling naptha, may be changed into an oil refembling petroleum, by mixing it with a finall portion of the acid of vitriol; with a larger proportion of the acid the mixture becomes black and tenacious, like Barbadoes tar; and the proportions of the ingredients may be so adjusted, that the mixture will acquire a folid confiftence, like afphaltum. This experiment teaches us to conclude that naptha, petroleum, Barbadoes tar, and asphaltum, differ chiefly from

A 3

each other, with respect to the quantity of acid which enters into their composition; and the substances procured by distilling pitcoal, or resinous vegetables, may furnish no improbable conjecture concerning the origin of these bitumens.

Let us suppose then a subterraneous fire to be fituated in or near a stratum of pitcoal, of turf, of fossil wood, or of any other such bituminous matter; it is manifest that the inflammable air, and the different kinds of oils, which were collected by distilling small portions of these substances, would be elevated by the heat into the crevices of the superincumbent strata; the light and pale oil would be a fort of naptha, or petroleum, the black and tenacious oil would be a Barbadoes tar, and

and this might be fo dried by the heat as to become an asphaltum. The oils, not being miscible with water, would be found floating upon its furface, as it issued out of the bowels of the earth, and being very inflammable, might constitute burning wells, fuch as have been met with near Wigan, at Brosely, and in many other places: or where the oil did not meet with water, or was too heavy to float on it, we may conceive that it would impregnate the porous strata of several kinds of stones and earth. It has been observed in another place\*, that they formerly obtained a fort of tar, from a stone at Brosely. and the stratum, which is called shale in Derbyshire, is so strongly impregnated with oil, that it will burn

A 4

of

<sup>\*</sup> Vol. 2. p. 347.

of itself, when set on fire; the workmen in digging through the black stone, which is incumbent on the shale, sometimes meet with cavities containing a thick black oil, which has oozed out of the furrounding stone. One of the greatest foughs, or fubterraneous passages, which has, perhaps, ever been formed in Great Britain, is that which is called Hellcar fough, in Derbyshire; this fough is driven through a stratum of shale, and the workmen are much troubled with inflammable air, which generally breaks into the fough, through the same crannies which give passage to little streams of water: they secure themfelves from the air, by keeping great fans constantly in motion; for the inflammable air, being lighter than common air, floats near the roof of the

the fough, and being drawn down from thence, and mixed with the common air by the motion of the fans, it is circulated in the fough without danger. I am fensible that inflammable air may be produced by various other ways, as well as by the application of heat, to bituminous strata; but as bitumens do yield inflammable air by distillation, it is probable enough, that fuch as is met with in bituminous strata, may, fometimes at least, be referred to the action of a fire, fituated, perhaps, at too great a distance from the surface of the earth, to produce any other sensible effect.

In the duchy of *Modena* in Italy, there is a remarkable rock, which confirms very much the notion of oils and pitchy substances, being separated

parated from bitumens, by a kind of fubterraneous distillation. The inhabitants of the district, by piercing the sides of this rock, at different distances from its summit, obtain oils of different natures, thickening and growing heavier, and deeper coloured, as the canals through which they flow, approach to the furface of the earth; at the distance of a few feet below the furface, they find a very thick oil, which in digging deeper becomes foft as butter, and at still a greater depth, it is found to be as folid as pitch.

Besides pitcoal and asphaltum, there are three other solid bitumens which deserve to be mentioned — Jet — Amber — Ambergris. Jet so much resembles cannel-coal in its colour, in its hardness, in its receiving a polish,

polish, in its not soiling the fingers when rubbed upon it, and in other properties, that many authors confound the two substances together; and indeed they agree in fo many qualities that it is somewhat difficult to fay in what they disagree. Jet however, when warmed by friction, has the property of attracting bits of straw, feathers, and other light bodies; but I never observed this property in any of the cannel-coals which I have tried. This property, if it may generally be relied on, as appertaining to jet, and not to cannel-coal, is a very easy characteristic, by which these substances may be distinguished from each other. Jet is faid to be found only in small detached pieces, and that it is thereby diftinguishable from cannel-coal, which which is found in large beds. Some think that the woody, fibrous tiffue of jet, may serve to distinguish it from cannel-coal, but whoever examines large quantities of this kind of coal, will see many pieces which much resemble wood in texture. The weight of a cubic foot of cannel-coal is, 1273 ounces, a cubic foot of jet, is said by one author to weigh 1238\*, by another 1180 ounces†.

The natural history of Amber is very obscure. This bitumen was for a long time thought to be restricted to the coasts of Prussia, on the Baltic sea. It was supposed to owe its origin to the exudations of certain trees on the coasts of Sweden, which falling into the sea were there hardened by the continual action of the

Martin. † Lewis, Newm. Chem.

the falts, and thence carried by particular winds to the open coasts of Prussia. This opinion was supported by, and formed to account for, the ants, flies, spiders, leaves of trees, and other terrestrial matters, which are almost always found inclosed in pieces of amber, and which no doubt must be admitted, as proving its being originally in a fluid state. In Prussia they not only gather amber on the sea coast, but they frequently find it at the depth of eight or ten feet beneath the furface of the earth, but at no great distance from the sea. The superincumbent strata are fand, clay, fossil-wood, pyrites, sand again, in which the amber is found, fometimes in detached pieces, fometimes in little heaps. This distribution of the strata, where amber is found, together

gether with their proximity to the fea, has made it with fome degree of probability be imagined, that this mineral owed its fituation to the inundation and recession of the fea, and that it was derived, partly from an oil arising from the decomposition of vegetables, by subterraneous fires, and partly from a mineral acid. Amber is frequently found in Italy, where they have no fossil-wood, but great plenty of petroleum.

The natural history of Ambergris, is as uncertain as that of amber, unless we admit the description which has been lately given of its origin, as the true one. We are told that ambergris is a part of the Cachalot or Spermacetiwhale. "It is found in this animal, in the place where the seminal vessels are usually situated in other animals.

It

It is found in a bag of three or four feet long, in round lumps, from one to twenty pounds weight, floating in a fluid rather thinner than oil, and of a yellowish colour. There are never feen more than four at a time in one of these bags; and that which weigh-'ed twenty pounds, and which was the largest ever seen, was found fingle. These balls of ambergris are not found in all fishes of this kind, but chiefly in the oldest and strongest"\*. This account seems probable enough, for ambergris is a fine perfume, and we know that other perfumes, fuch as civet, musk, and castor, are fituated in the inguinal regions of the civet cat, the musk animal, and the beaver.

All vegetable, and bituminous, and

Goldsmith's Nat. Hist. Vol. vi. p. 220.

and indeed all animal fubstances leave, after their volatile principles have been separated by distillation, a black coal. These coals differ somewhat from each other, with respect to their proneness to catch fire, and their ability to support it, but I will content myself with examining the nature of the residue, from the distillation of wood.

This residue does not differ from what is generally called charcoal; the slightest attention to the manner of obtaining this residue, and of making charcoal, will convince us, that no difference ought to be expected. When the wood is distilled, its communication with the external air is obstructed, its volatile parts are elevated from it, by the heat to which it is exposed, and the residue is that part

part of the wood which remains after all the volatile parts are driven off. In making charcoal they construct a pile of wood upon the surface of the ground, they cover the pile with a coating of turf, or other fubstances, and make the coating so compact, that it will not admit of air, except through fome little round holes, which are purposely made in it, and which can be stopped at pleafure. When the pile, thus constructed, is set on fire, part of the oil of the wood is confumed during the burning of the pile, the other part, together with the air and water contained in the wood, is evaporated, and there remains, when the operation is finished, the earthy part of the wood, called in that state, charcoal. Thus the making of charcoal VOL. III. B 15

is a kind of distillation, for the coating which surrounds the pile of wood, may be compared to a retort.

Henckel informs us, that 150 lbs. of oak, will produce 62 lbs. of charcoal\*; but he does not inform us whether the oak was dry, or green, whether it had its bark on, or was peeled, whether it was all heart of oak, or partly heart, and partly fap, whether the operation of making the charcoal was discontinued as soon as the wood ceased to smoke, or protracted some time longer, and yet a difference in any one of these circumstances, will sensibly influence the weight of the charcoal, procurable from a definite weight of wood.

The woods which I converted into charcoal were dry, and had been felled

<sup>\*\*</sup> Flor. Satur. c. iv. p. 55.

led many years, their relative weights were taken with great exactness.

Weight of a cubic foot of

Water - - - 1000 avoir. ounces.

Box - - 950
Oak — 892
Ash — 832
Mahogany — 816
Walnut - 790
Deal — 615

Authors differ very much as to the weights which they have affigned to definite bulks of the same kind of wood. Thus, one estimates the weight of a cubic foot of dry box at 1030\*; another at 1201 ounces †: one puts the weight of a cubic foot of dry oak at 925‡; another at 800 ounces ||. To the more obvious

B 2 fources

<sup>\*</sup> Cotes Hydros. p. 73. † Ferguson's Tab. p. 237. ‡ Cotes. || Emerson's Mech. p. 132.

fources of this diversity, in the weights of equal bulks of the same kind of wood, — such as the wood being green or dry, — being cut from the boll or branch of a tree; one may be added, which has not, I believe, been sufficiently attended to — I mean the great loss of weight which, in certain circumstances, the same piece of wood sustains, by a simple exposure to the atmosphere, in the course of a few days.

From the middle of a branch of an oak tree, which had been felled in April, and exposed, without its bark, to the hot summer of 1779, I cut, Sept. 4, a round piece, about six inches in diameter, and three in thickness: Sept. 15, I cut from the heart of this piece of oak a small slip, 3 inches in length, \(\frac{1}{4}\) of an inch in thick-

thickness, and 79 grains in weight; at the same time, I cut a similar slip from the sap of the same piece, the weight of which also was 79 grains. These two pieces were put into the drawer of my study table, and being weighed again, Sept. 25, the heart of oak had lost 8 grains, or near is of its weight; the fap had loft 12 grains, or above  $\frac{1}{7}$  of its weight. Now if the weights of feveral equal bulks of these woods had been taken on the 15th, and on the 25th of September, it is obvious, (notwithstanding the contraction they might have fuffered) that there would have been fome difference in them, though the woods themselves appeared equally dry on both days.

This speedy diminution of weight which wood undergoes by exposure

B 3

to the air, being a matter of some importance in an œconomical view, I will mention another experiment which I made on the subject. A piece of ash cut, March 17, 1780, from the middle of a large tree, which had been felled fix weeks before, was accurately weighed; its weight was 317 grains, its length 3 inches, and its breadth 2. It was weighed again, March 24, it had loft in the course of seven days 62 grains, or near 5 of its weight. I weighed this fame piece of wood on the 25th of August in the same year, but it had not lost any thing of its weight, from the 24th of March to the 25th of August. The two pieces of oak, mentioned in the last experiment, were weighed also, on the 25th of August, 1780, they had neither of them

them lost, in the course of eleven months, quite 1 grain; hence it appears, that the matter which is difpersed from wood after it is cut, is foon evaporated; this matter probably consists chiefly of water. The carriage of wood, especially by land, is very expensive: if an oak or an ash tree was cut into boards, or fcantlings, upon the spot where it is felled, there would be a faving of the carriage of one ton in fix or feven, from the evaporation of the fubstance of the wood; to say nothing of chips. and other refuse parts.

It is well known, that all wood becomes heavier than water, by having the air extracted from its pores, either by an air-pump, or by boiling it in water. The woods of which I have given the relative weights,

B 4.

were all of them rendered heavier than water, by a long continuance in cold water; for the heat of the water in which they were put, never exceeded 60 degrees. They funk in the water after they had been foaked in it for different lengths of time, but it required above 100 days foaking, before the deal would fink. After they had all lain in water for 110 days, I took them out, and let them dry by the gradual heat of the atmosphere for above a month; I then weighed them, and found that box, oak, and ash, had each of them lost  $\frac{1}{32}$  of the weight they had before they were put into the water; but that mahogany, walnut, and deal, had lost only 1/96 of their weight. This loss of weight is occasioned, partly by the escape of some portion

of air, and partly by a diffolution of fome of the other principles of the woods; for the water, in which they were placed, had evidently acted upon them, its colour and confiftence being both changed. Most woods contain both a gummy and a resinous part; and gums being soluble, and refins not foluble in water, we can have no difficulty in apprehending the reason, why some forts of wood lose a greater proportion of their weight, by being immersed in water, and afterwards dried, than others. Since the same piece of wood has very different weights, when dry and when foaked with water; the covering carts, ploughs, and other husbandry gear, usually made of ash, with a coarse kind of paint which will keep out the rain, is a practice practice full as ferviceable in lessening the weight of the implement which is to be moved by the strength of a man or horse, as in preserving the wood of which it is made from decay.

I took square pieces of the woods before mentioned, each piece being 3. inches in length, and weighing exactly 96 grains, and exposed them, when covered with fand, in a crucible, to the action of the fame fire, which was ftrong enough to keep the crucible red hot, for three hours; they were, at the end of that time, all of them converted into perfect charcoals; the weights of the respective charcoals were taken, whilft they were still warm, from the operation, and are expressed in the following table,

Walnut

Walnut	96 grn	s. gave 25	grns.of charcoal
Oak —	96 -	- 22	(materials)
Box	96 -	- 20	garantee and a second
Mahogany	96 -	- 20	-
Ash —	96 -	- 17	
Deal -	96 —	- 15	terminant)

There is a good reason for remarking, that the charcoals were weighed whilst they were warm, for in weighing them a few days afterwards, I found that they had all increased in weight in consequence of something which they had attracted from the atmosphere; their weights then were, — walnut 28 — oak 24 — box 23 — mahogany 24 — ash 18 — deal 16 — grains.

The quantities of residue remaining from the distillation of 96 ounces of oak, box, and mahogany, were respectively 30,  $26\frac{1}{2}$ , and  $27\frac{1}{2}$  oun-

ces, which numbers are feverally larger than those, expressing the quantities of charcoal, obtainable from 96 parts of those woods; this difference may proceed from the woods, employed in the two procesfes, being of different qualities, or, more probably, from the heat in which the charcoal was made, being greater than that employed in the distillation; for the stronger the fire, the less is the quantity of charcoal, which a definite weight of wood will yield.

In making charcoal the workmen observe, that the pile of wood is sensibly diminished in size by the operation; this proceeds from the shrinking of the wood. All the kinds of wood which I charred were diminished in all their dimensions, the

the mahogany, oak, and walnut, were the least diminished, and the box was the most diminished; I thought it had lost an eighth part of its length. This diminution not only depends upon the nature of the wood, but it is influenced by the strength and continuance of the heat, that being most diminished, which has sustained the greatest heat.

Though charcoal, from every fort of wood, is incapable of being decomposed, by the strongest sires in close vessels, yet it is a compounded body, and may be decomposed by being burned in the open air.

Van Helmont says, that 62 pounds of oak charcoal will, by burning, yield only 1 lb. of white ashes. The other 61 pounds which are dispersed into the air, he considers as a vapour of an elastic nature, which can neither be collected in vessels, nor reduced into a visible form. This vapour he called by a new name, gas\*.

Stahl is of opinion, that 10 lbs. of charcoal made from porous woods, fuch as fir and fallow, will not, when burned with a very flow fire, yield above 1 pound of ashes; this quantity however, it must be remarked, is above six times the quantity assigned by Van Helmont to oak which probably contains more ashes in a definite weight of charcoal, than either fir or fallow.

## Geoffroy,

<sup>\*</sup> Hunc spiritum, incognitum hactenus, novo nomine gas, voco, qui nec vasis cogi nec in corpus visibile reduci potest. Van Hel. Op.om. p. 103. Some derive gas from the Dutch ghoast-spirit; others from the German gascht, a frothy ebullition.

<sup>+</sup> Stahlii Exper. Numero CCC. p. 17.

Geoffroy, from somewhat less than 34 ounces of the charcoal, remaining after the distillation of the heart of guaiacum, got near 3 ounces of white ashes, by calcining the coal in an open fire for 12 hours. From near 23½ ounces of the coal, remaining from the distillation of the sap of guaiacum, he got near 1½ ounce of ashes. And 29½ ounces of the coal, from the bark of guaiacum, gave him 13½ ounces of white ashes \*.

Lastly, M. Sage assures us that 100 pounds of charcoal will not, when burned, furnish quite 2 ounces of ashes +.

These accounts, it must be acknow-

<sup>\*</sup> Geof. Mat. Med. or treatife on foreign vegeta. by Thickness, p. 112.

<sup>†</sup> Exper. fur l' Alk. Vol. fluor. p. 27.

knowledged, differ very much, as to the quantity of ashes obtainable from a definite weight of charcoal; and the difference, I think, is much greater than what can wholly be attributed to the different textures of the feveral woods; a part of this diverfity may, probably, arife from a difference in the manner of burning the charcoal. When charcoal is burned in small quantities, and in a flow fire, less of its substance will be dispersed into the air, than when the quantity is larger, and the stream of air which fupports the fire, is more rapid. This feems not improbable; but if the weight of the ashes, remaining from the burning of a definite weight of charcoal, be at all influenced by the degree of fire, it feems reasonable to suppose, that what

what is driven off by the violence of the fire, is of the same earthy nature, as that which remains when the fire is more moderate; at least it may be argued, that when charcoal is burned with a flow fire, fome of its principles, its oily principle for instance, though it, probably, also contains a faline one, are more completely decomposed, than when it is confumed with a violent fire, and that the decomposition of these principles, gives an additional quantity of earth or falt to the ashes.

If there be any truth in this notion, we must not say, that the 61 pounds of matter which, according to Van Helmont, are dispersed into the air from 62 pounds of charcoal, are wholly of an elastic nature; since they may consist principally of an VOL. III. C attenu-

attenuated earth, which being driven off by the current of air, requisite for the maintenance of the fire, remains for a time suspended in the atmospherical air, without being in its own nature elastic. I would not be understood to fay, that the whole of what is diffipated, during the burning of the charcoal, is an attenuated earth, fince it is certain, that the earth of the ashes is not inflammable, and that charcoal contains fomething which is inflammable; it is allowed alfo, that fimple earth is inodorous, and it is well known, that charcoal, during its inflammation, disperses fomething into the air which has a strong smell; this something by which charcoal is rendered inflammable, and by which the air is infected with a particular fmell, during the burning of the charcoal, is called by most chemists the phlogiston \*. This C 2 phlogiston

\* Phlogiston is a constituent part of metallic substances, and it seems, when separated from them, to be of an elastic nature. I distilled zinc with strong acid of vitriol, and obtained a portion of fulphur, produced, as it should seem, by the acid's uniting itself with the phlogiston of the zinc. No inflammable vapour was produced, till the fulphur began to be sublimed, then, indeed, there escaped a vapour, composed, I think, of the attenuated parts of fulphur, which upon the approach of a candle took fire. Another portion of zinc was distilled with weak acid of vitriol; before the zinc felt the heat of the fire, the inflammable air, separable from zinc by a weak acid of vitriol, passed into the receiver, and being fet on fire, burst it with a great explosion: another receiver was applied, and the distillation continued to dryness, but not a particle of fulphur was produced, the phlogiston necessary for its formation having, probably, been feparated from the zinc, by the violent action of the acid,

phlogiston, whether it be an elastic inflammable fluid, or an unelastic earth of a particular kind, constitutes, probably, but a very small portion of the weight of what is difperfed into the air, from burning charcoal: we all know what a strong fmell may be diffused through a large room, from the ignited snuff ot a candle, or from a very small piece of charcoal, which has not been thoroughly burned; the vapours issuing from these substances are of an oily saline nature, and are visible: the vapour of charcoal, though it is too fubtle to be feen, may be of a nature fomewhat fimilar, and capable

acid, and confumed at once by the inflammation. May it not from the comparison of these experiments be conjectured, that the phlogiston of metals is an elastic inflammable air? ble of a very extensive diffusion through the air. An infant has been known suddenly to expire, from the smoke of a candle, blown out under its nose, and the vapour of charcoal is most dangerous, when the charcoal has not been thoroughly burnt.

It has been found by experiment, that the common atmospherical air is much altered in its properties, by being made to pass through red hot charcoal, into the vacuum of an air pump; it then extinguishes the slame of a candle, and animals die in it\*. A similar change takes place, when charcoal is consumed in an apartment, which has not a sufficient supply of fresh air; the instances of perfons who have unhappily lost their lives in such air, are very common in

C 3 all

<sup>\*</sup> Hauksbee's Exper. p. 287.

all countries, where much use is made of charcoal, but especially in Russia, where their apartments are heated by ovens, containing red hot charcoal\*. The change which the atmospherical air undergoes, from the burning of charcoal, may proceed either from the air, having loft fome of its constituent parts in coming in contact with the burning charcoal, or from its having gained fomething from the charcoal, or from its having done both at the same time; just as water which passes through a lump of falt or fugar, loses a great

<sup>\*</sup> Philos. Trans. 1779, p. 325 — Where there is mention made of the Russian method of recovering persons who have been rendered senseless by the vapour of the charcoal, it confists in carrying the person into the open air, rubbing him with snow or cold water, and pouring water or milk down his throat.

a great part of the air it contains in its natural state, and gains a portion of the salt, which becomes dissolved in it, and upon both accounts suffers a change of its properties.

It is generally admitted, that charcoal and all other bodies, nitrous ones excepted, cease to burn, as soon as they cease to be supplied with fresh air, and the air has, chiefly on this account, been thought to communicate fomething to the fire, by which the fire was maintained, and the air was confumed. And this opinion has been confirmed by obferving, that a definite quantity of air was much diminished in bulk by bodies being burned in it. Thus, if 10 cubic inches of air be made to pass through red hot charcoal, they will be reduced to nine, and there

C 4

are means of making the diminution still greater.

Doctor Hooke advances another Hypothesis; he allows air to be necessary to the support of fire, but he thinks that it contributes to this support, not by imparting any thing of its own substance to the fire, but by dissolving the inflammable principle of bodies, as water dissolves salts\*: according to the former hypothesis air is the food, according to this it is the receptacle or folvent of fire.

Doctor Priestly, to whose inventive genius and indefatigable industry the philo-

\* Hooke's Micogr. p. 103. and Posthu. Works p. 169. Juncker seems to have entertained a similar notion — ingens aëris quantitas requiritur ad disolvendas et recipiendas ignitas illas et ultimo motu attenuatas particulas, unde nisi sat aëris sit extinguitur ignis. Junck. Cons. Chem. Vol. I. p. 157.

philosophic world is peculiarly indebted for his inquiries into the nature of factitious airs, has observed, that common air is diminished one fifth by the fumes of burning charcoal; and this diminution, he thinks, is some how or other effected by the air being highly charged with the phlogiston of the charcoal; and he observes, which agrees very well with Dr. Hooke's hypothesis, that when any definite quantity of air is fully faturated with phlogiston from charcoal, no heat that he had ever applied was able to produce any more effect upon the charcoal\*.

Though common air is diminished in bulk by the fumes of burning charcoal, and of other bodies in a state of combustion, yet a bottle or a bladder filled

<sup>\*</sup> Philos. Trans. 1772. p. 225. — 230.

filled with this diminished air, weighs less than when it is filled with common air\*, in the proportion of 183 to 185. That 5 cubic inches of common air, should be reduced by the fumes of burning charcoal to 4 cubic inches, and that these 4 cubic inches of infected air, should weigh less than 4 cubic inches of common air, cannot well be accounted for without admitting, that a part of the 5 cubic inches of atmospherical air, has been, by some means or other, taken away, at the same time that its bulk was reduced to 4 cubic inches.

Being defirous of feeing, whether the property I had observed in charcoal, with respect to its weighing less when it was quite cold, than when it was warm from the fire in which

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<sup>\*</sup> Priest. Exp. and Ob. vol. II. p. 94.

it had been made, was a general property appertaining to all hot and cold charcoal, I weighed feveral pieces when they were cold, and again, when they were fo hot as to be handled with difficulty, and found that they all lost (they were of the fame kind of wood) about I part in 12 of their weight, and that being left to cool in the open air, they regained what they had loft in a few days. This acquisition of weight was made most rapidly at first, a piece which weighed 240 grains when cold, was reduced by being heated, to 220 grains, and being left to cool, it gained 9 grains in 4 hours, and 15 grains in 8 hours. From the manner in which charcoal is made, it is probable that what remains adherent to the wood, is not greatly differdifferent from what is forced from it by the last degree of heat; now this confifts of an acid and an oil rendered thick and pitchy, by its union with an acid; may we not hence suppose, that it is a portion of fixed acid, which attracts the humidity of the air, or perhaps the air itfelf, when the charcoal is hot, and becomes faturated therewith, and that what was attracted, is again driven off when the charcoal is again heated; and thus the charcoal becomes again capable of exerting its attraction, and acquiring an increase of weight? It is some confirmation of this hypothesis, that charcoal when taken out of hot fand, takes fire upon exposure to the air, and for much the fame reason, probably, that Homberg's pyrophorus takes fire

contains a stronger acid than most kinds of wood, and Geosfroy has observed that "the coal of guaiacum being taken out of the retort, and exposed to the air, even two or three days after the process, takes fire immediately of its own accord; provid-

\* Homberg's Pyrophorus is known to every school-boy, it is made by calcining together, for a proper time, and in proper quantities, either alum or any falt containing the vitriolic acid, with honey, fugar, flour, or any animal, or vegetable substance, capable of being reduced to a coal. Part of the vitriolic acid being uncombined with the phlogiston of the coal, and being in a dry condensed state, attracts the humidity of the atmosphere, and generates such a degree of heat, by its mixture with water, as is fufficient to inflame the other part of the pyrophorus. Pyrophori may be made without the vitriolic acid, but fome acid probably enters into their composition.

provided, that when the diffillation is over, the neck of the retort be carefully stopped, and the vessels and furnace be left to cool of tlemfelves"\*.

This property of increasing in weight by exposure to the air, belongs to the hot coal of pitcoal, as well as to that of wood; I took some red hot cinders, and weighing them in that state, left them to cool; in 12 hours they had gained one seventy sifth part in weight, and in 4 days they had gained one thirtieth of their weight. Some coak which had been burned with a strong sire, gained much less than the cinders.

It has been observed in another place, that charcoal may be decomposed, by being distilled with the

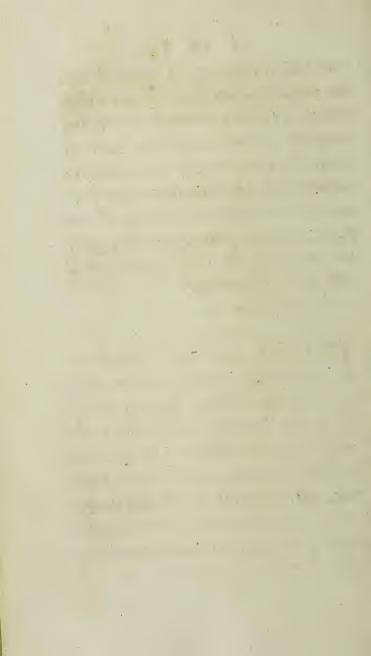
<sup>\*</sup> Treatise on foreign vege. p. 111.

acid of vitriol\*; this acid robs the charcoal of its inflammable principle, and reduces it to an earth: no other menstruum seems to have any action upon it. What alteration might be produced in charcoal, by quenching it when red hot, in various menstruums, or by boiling it in them, or by keeping it immersed in them, when cold, for a long time, or by other less obvious processes, it does not fall within my design to inquire.

Animals and vegetables are foon reduced by putrefaction to an earth, many forts of stones and metallic substances are crumbled into dust by the action of air and water; but charcoal remains unchanged for ages, whether it be exposed to the air, or immersed in water, or buried in the earth. The beams of the theatre

at Herculaneum were converted into charcoal by the Lava, which overflowed that city, and during the lapse of above seventeen hundred centuries the charcoal has remained as entire as if it had been formed but yesterday, and it will probably continue fo to the end of the world. This incorruptibility, as it may be called, of charcoal has been known in the most distant ages; for it has been observed that the famous temple of Ephefus was built upon wooden piles which had been charred on the outside. The custom of charring the ends of posts which are to be fixed in the earth is very common, and I have often wondered that the fame custom has not prevailed with respect to the wood used in mines and subterraneous drains. The timbers bers which support, in many places, the roof of the soughs through which there is a current of water, are wasted away in a few years, that part of them especially which is exposed to the alternatives of moisture and dryness by the rising and falling of the water is soon rotted, and this part one would think might be charred with great advantage.

VOL. III. D ESSAY





## ESSAY II.

Of the Quantity of Water evaporated from the Surface of the Earth in hot Weather.

HERE are many operations constantly carrying on by natural means, which, though they escape the ordinary observation of our senses, sufficiently excite our associations when once discovered. The vast quantity of a particular kind of air, with which the atmosphere is daily impregnated, from the combustion of all sorts of suel, is

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one instance of this kind; and the water which is raised into the atmosphere from the surface of the earth, is another. Who would have conjectured that an acre of ground, even after having been parched by the heat of the fun in fummer, difperfed into the air above 1600 gallons of water in the space of twelve of the hottest hours of the day? No vapour is feen to afcend, and we little suppose that in the hottest part of the day, more usually does ascend than in any other. The experiment from which I draw this conclusion, is so easy to be made, that every one may fatisfy himself of the truth of it. On the 2d of June, 1779, when the fun shone bright and hot, I put a large drinking glass, with its mouth. downwards, upon a grafs-plat which

was mown close, there had been no rain for above a month, and the grass was become brown; in less than two minutes the inside of the glass was clouded with a vapour, and in half an hour drops of water began to trickle down its inside, in various places. This experiment was repeated several times with the same success.

That I might accurately estimate the quantity, thus raised, in any certain portion of time, I measured the area of the mouth of the glass, and sound it to be 20 square inches: there are 1296 square inches in a square yard, and 4840 square yards in a statute acre; hence, if we can find the means of measuring the quantity of vapour raised from 20 square inches of earth, suppose in

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one quarter of an hour, it will be an easy matter to calculate the quantity which would be raifed, with the same degree of heat from an acre in 12 hours. The method I took to meafure the quantity of vapour, was not perhaps the most accurate which might be thought of, but it was simple and easy to be practifed: when the glass had stood on the grass-plat one quarter of an hour, and had collected a quantity of vapour, I wiped its infide with a piece of muslin, the weight of which had been previously taken; as foon as the glass was wiped dry, the muslin was weighed again, its increase of weight shewed the quantity of vapour which had been collected. The medium increase of weight, from several experiments made on the same day, between

between 12 and 3 o'clock, was 6 grains collected in one quarter of an hour, from 20 square inches of earth. If the reader takes the trouble to make the calculation, he will find that above 1600 gallons, reckoning 8 pints to a gallon, and estimating the weight of a pint of water at one pound averdupoise, or 7000 grains troy weight, would be raised, at the rate here mentioned, from an acre of ground in 12 hours.

It may easily be conceived that the quantity thus elevated, will be greater when the ground has been well foaked with rain, provided the heat be the same; I did not happen to mark the heat of the ground when I made the forementioned experiments; the two following are more circumstantial: the ground had been wet-

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ted the day before I made them, by a thunder-shower, the heat of the earth at the time of making them, estimated by a thermometer laid on the grass, was 96 degrees; one experiment gave 1973 gallons from an acre in 12 hours, the other gave 1905. Another experiment made when there had been no rain for a week, and the heat of the earth was 110 degrees, gave after the rate of 2800 gallons from an acre in 12 hours; the earth was hotter than the air, as it was exposed to the reflection of the fun's rays from a brick wall.

The heat in Bengal in the summer months is variable, in the shade from 98 to 120 degrees, \* and in the sun it probably does not fall short of

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<sup>\*</sup> Philof. Trans. 1767. p. 218, and for the year 1775. p. 202.

140 degrees; hence, after the earth has been well drenched by the overflowing of the Ganges, immense quantities of vapours must be daily raifed, to the amount, perhaps, of five or fix thousand gallons from an acre, in twenty four hours. The rainy feafon in Bengal lasts from the beginning of June to the middle of October, all this interval is confidered as an unhealthy time, but especially the latter part of it; for then the earth begins to grow dry, the slime left upon its surface, consisting of decayed vegetables and other putrefcent bodies, begins to corrupt, and the fun by its violent and continued action raises up into the air, not a pure water, but water impregnated with putrid particles of all kinds.

Whether a merely moist situation

be unwholesome may be much questioned, but that moisture arising from earth or water in a state of putrefaction is fo, cannot well be doubted. The overflowing of the Nile puts a stop to the plague in Egypt, inafmuch, probably, as it puts a stop to the putrefaction of the canals of Grand Cairo and other places. Agues and putrid fevers are much more frequent in the fens of Cambridgeshire and Lincolnshire in very dry, than in wet years; the Irish, who annually come to reap the harvest in the fens of Cambridgeshire, have been so sensible of the difference. that for the three or four years last past, which have been very dry, they have entered upon their task with great reluctance and apprehension of what they call the Fen-shake. The States u

States of Holland, in the year 1748, laid the country around Breda under water, and ordered the water to be kept up till the winter, in order to stop a sickness which had arisen from the moist and putrid exhalations of half drained grounds \*. The Arabs are faid to take a horrid kind of . vengeance when they think themfelves injured by the Turks at Baffora; they contrive to overflow the adjoining country: a pestilential fever begins to shew itself as the land begins to grow dry by the evaporation of the water, and it rages with fuch violence as to carry off many thoufands of the inhabitants of that city +.

The nature of the foil must have a great influence on the health of the people

<sup>\*</sup> Sir J. Pringle's Dis. of the Army, p. 63. Philos. Trans. 1778, p. 215.

people who inhabit it, fo far as that is dependent on the moisture or dryness of the air. There is, probably, as much water raised into the air, in a hot day, from an acre of ground in the fens of Cambridgeshire, as is raised in two or three days from an equal furface in the fandy parts of Norfolk and Suffolk. Not but the most fandy country may have a very moist atmosphere, when water happens to be found near the furface; for the heat of the fun will penetrate through the fand, and raise the water in vapour, which will find an easier passage through the sand than it would do through a less open soil. Thus the foil in some parts of Dutch Brabant is a barren fand, but water is every where to be met with at the depth of two or three feet, and in proporproportion to its distance from the furface the inhabitants are free from diseases\*.

Vegetation must be greatly influenced by the quantity of water which is raised from the earth; some soils retain humidity much longer than others, and one great use of marles and other manures, is to render the foil on which they are put less liable to be deprived. of its moisture by the heat of summer. The water, in afcending from the bosom of the earth, moistens the roots, and in being disfolved in the air, it affords nutriment to the branches of vegetables; but as vegetation may be injured either by a defect, or an excess of moisture, and as different plants require different quantities of it, for attaining their utmost perfection

<sup>\*</sup> Diseas. of the Army, p. 62.

perfection, it merits the attentive observation of the farmer, to suit his plants and his manures to the nature of the soil. There are many sandy and limestone soils, which are covered almost with flints or limestone pebbles; the crop of corn would, probably, be less, if these stones wereremoved; for they are serviceable, not only in sheltering the first germs of the plant from cutting winds, but they impede the escape of moisture from the earth; the ascending vapour strikes upon that surface of the stone which is contiguous to the earth, and is thereby condensed, and thus its further ascent is for a time, at least, prevented.

Upon the same grass-plat, and contiguous to the glass used in the experiments, I placed a silver cup,

with.

with its mouth downwards, of a shape similar to that of the glass, and nearly of the same dimensions; but I could never observe that its inside had collected the least particle of vapour, though I frequently let it stand on the grass for half an hour, or more.

By means of a little bees' wax, I fastened an half crown very near, but not quite contiguous, to the fide of the glass, and setting the glass, with its mouth downwards, on the grafs, it presently became covered with vapour, except that part of it which was near to the half crown. Not only the half crown itself was free from vapour, but it had hindered any from fettling on the glass which was near it, for there was a little ring of glass surrounding the half crown

crown to the distance of \$\frac{1}{4}\$ of an inchwhich was quite dry, as well as that
part of the glass which was immediately under the half crown; it
seemed as if the silver had repelled
the water to that distance. A large
red waser had the same effect as the
half crown, it was neither wetted
itself, nor was the ring of glass contiguous to it wetted. A circle of
white paper produced the same effect,
so did several other substances, which
it would be tedious to enumerate.

These phenomena, respecting the different dispositions of different bodies to attract the rising vapour, are similar to what others have taken notice of concerning the falling of dew, and are, probably, to be explained upon the same principles, whatever they may be. Muschenbroek

brock placed on the leaden terras of the Observatory at Utrecht vessels of glass, china, varnished wood, polished brass, and pewter; he found that in the course of a night the glass, china, and varnished wood, had collected a great abundance of dew, but that not a drop had fallen on any of the polished metals\*. M. du Fay exposed to the air, when the dew was falling, two large funnels, one made of glass, the other of polished pewter; the necks of the funnels being inserted into vessels proper to retain any moisture which might be collected by them: he fometimes found in the morning that the vessel under the glass funnel contained an ounce or more of water, E VOL. III. but

<sup>\*</sup> Introd. ad Philos. Nat. tom. 2. p. 990.

but he never observed so much as a drop in the other\*.

A great part of the water which is raised into the air from the perspiration of the earth, during a hot day, descends down again upon its furface in the course of the night; and this is the reason that the dews are the greatest in the hottest weather, and in the hottest climates. The earth retains the heat it receives in consequence of the sun's action longer than the air does; water, moreover, is evaporable in all degrees of heat; hence water may continue to rise from the earth, when the air, being cooled by the absence of the fun, is no longer able to fustain what is thus raised, or to retain what

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<sup>\*</sup> Hist. de l'Acad. des Scien. 1749.

It had taken up during the day time, and a dew from these different causes may, under certain circumstances, be found both to rise and fall during the whole night.

Egypt, at one feafon of the year, is fo parched up by the heat, that the furface of the ground becomes quite rugged with fiffures; at this time the dew, proceeding from the vapour exhaled from the earth, is very plentiful, and by its plenty prevents the total destruction of the country. 66 This dew is particularly ferviceable to the trees, which would otherwise never be able to resist the heat; but with this affiftance they thrive very well, bloffom and ripen their fruit. Therefore, the upper parts of the Egyptian trees, at one time of the year, do the office of

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roots, attracting nourishment by their absorbent vessels, the leaves, from the moist air."\*

The quantity of water which was condensed on the inside of the glass, I found to be accurately proportionable to the time during which it stood on the grass; for in one experiment 6 grains were collected in 10 minutes, and in another 15 grains were collected in 25 minutes; now the proportion of 6 to 10 is the same as that of 15 to 25.

In order to see whether the copious vapour collected by the glass was owing to the natural perspiration of the grass, or to a kind of mechanical distillation from the body of the earth, I put the glass upon a footpath which was dry, and had no grass

<sup>\*</sup> Hasselquist's Voy. p. 455.

grass growing upon it, the vapour rose from the footpath as well as from the grass, but not so abundantly.

From what has been advanced, it may, probably, be justly inferred, that the air contiguous to, or not far removed from, the furface of the earth, whether that furface be plain or mountainous, barren, or covered with vegetables, will be much more loaded with the vapour which arises constantly from the earth, than that which is at the distance of even a few yards from the surface. This point may be illustrated by the following hypothesis. - Suppose the earth to be a globe of rock falt, and to be covered with water to the height of a mile; imagine the water to be divided into 4 spherical shells, E 3

shells, each if of a mile in thickness. Now the first shell, which is supposed to be contiguous to the surface of the falt, would foon faturate. itself with the salt, and becoming thereby heavier than the water at a greater distance, it would not, by the ordinary motion of the winds and tides, foon mix itself with the whole mass of water; but it would contain far more falt in folution than the fecond shell, and the fecond. would contain more than the third, and the third more than the fourth. Let us further suppose the falt contained in the whole of the water to be precipitated, and the precipitation to begin from the shell farthest removed from the furface of the earth; it is evident, that the quantity of the precipitate will increase,

not fimply with the increase of space through which it has descended, but in a much higher proportion, inafmuch as the last shell, through which it descends, may be supposed to contain three or four times as much falt as the uppermost. In like manner, it feems reasonable to suppose that the air which is near the furface of the earth will be greatly more charged with water, which it dissolves as water diffolves falt, than that which is situated at the distance of even a few yards from the furface.

Dr. Heberden was the first perfon who took notice, that a much larger quantity of rain falls into a rain-gage situated near the surface of the earth, than into one of the same dimensions situated a few yards above

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it\*; and he thinks that this difference is to be explained from fome unknown property of electricity. The fact is placed beyond controverfy, by experiments which have been made at various places, at Liverpool in particular it has been observed, that "a vessel standing on the ground in a spacious garden, received double the quantity of rainwhich fell into another vessel of equal dimensions, placed near the same spot, but eighteen yards higher +." I am far from thinking that the foregoing observations, relativeto the quantities of water contained in equal bulks of air at different heights.

<sup>\*</sup> Philof. Trans. 1769. p. 361.

by Dr. Percival, who has explained the phenomenon from the known principles of Electricity. Essays by Dr. Perci. p. 112.

heights from the surface of the earth, contain a fatisfactory explanation of this phenomenon; yet it may be remarked, that rain-gages placed at equal distances from the surface of the earth, collected nearly equal quantities of rain, though one of them was situated on a plain, and the other on a mountain 450 yards in height above the plain\*: this observation is some confirmation of the hypothesis which has been mentioned, as on that supposition it follows, that the air at the same distance from the furface of the earth, is equally impregnated with water, other circumstances being the same, and therefore equal quantities of rain ought to be collected by vessels placed at equal distances from the furface

Philof. Trans. 1772. p. 294.

face of the earth; though according; to the fame supposition, a much. larger quantity ought to be collected. by a vessel placed on the surface, than by one placed a few yards above it. Thus this hypothesis, admitting, its truth, (which future experiments will perhaps establish) seems as if it. was fufficient for explaining the phenomenon; I would be understood. however to mention it with much diffidence, and was I as much skilled. in electricity, as the very worthy and ingenious person, who first noticed. the fact, is in every branch of natural philosophy, I might probably have feen reason not to mention it at: all.



## E S S A Y III.

Of Water dissolved in Air.

E have feen, in the preceding Essay, that large quantities of water are raised from the earth in the hottest weather: the water, which is thus elevated, is no more visible in the air, than a piecer of sugar is visible in the water wherein it happens to be dissolved, nor is the transparency of the air injured by the water it has received from the earth,

earth, and therefore we conclude, that the water is not merely mixed with the air, but really diffolved in it; a perfect transparency of the fluid, in which any body is diffolved, being esteemed the most unequivocal mark of its solution.

The cause of the ascent, suspension, and descent of vapours, is not yet fully determined; many think that electricity is the principal agent in producing these phenomena\*; whilst others are of opinion, that water is raised and suspended in the air, much after the same manner in which salts are raised and suspended in water; and it must be owned that this opinion

<sup>\*</sup> Philos. Trans. 1755. p. 124. — Electricitas, vapores in aërem extollit, in aëre suspendit, et exaëre in tellurem depluit. Pros. Bavers Exp. de Elec. Theo. p. 106.

opinion (which future experience may shew not to be wholly inconfistent with the other) has a great appearance of probability.

Salts, in general, are more speedily dissolved in warm water than in cold; and water, in like manner, is more speedily dissolved in warm air than in cold. We have a sensible proof of this, in the exhalation of dew, it being much sooner dried up in places exposed to the direct rays of the sun, than in the shade; because the air in the shade, being some degrees colder than that in the sun, is not able to dissolve the same quantity of water in the same time.

When water is faturated with any kind of falt in a definite degree of heat, then will it retain the falt as long as it retains its heat, but if the

heat

heat be lessened, the transparency of the folution will be destroyed, a part of the falt will become visible, and fall to the bottom, in consequence of its superior weight; what falls to the bottom will be redissolved, as soon as the water regains its heat. It is obvious that the quantity of the falt, which is precipitated from the cooling of the water, will depend partly on the degree of heat in which the folution is faturated, and partly on the degree of cold to which the folution is reduced. Thus water of go degrees when faturated with falt, contains more falt than it would do if it had only 70 degrees of heat, and in being cooled to 50 degrees, the precipitation of falt will be greater in the first instance, than in the second; though it might, probably, be the

the same, if the solution of so degrees was cooled only to 60, and that of 70 to 50. Something very analogous to all this may be observed, with respect to the solution of water in air. In misty weather, we frequently see the mist of the morning intirely vanishing towards the middle of the day, and coming on again towards the evening; the reason of which seems to be, that the air being warmed by the approach of the fun to the meridian, is able to dissolve the morning mist, but as the air grows colder again towards the evening, the water which had been perfectly dissolved by the midday heat, begins to be precipitated, the transparency of the air is destroyed, and an evening mist is formed.

This phenomenon has been ob-

Merved to prevail, in the coldest atmosphere that has ever yet been
taken notice of, on the surface of
the globe; for in January 1735,
when the cold in Siberia was equal to
157 degrees below the freezing point
in Farenheit's thermometer, the lower region of the air was obscured by
a perpetual cloud, which was very
thick in the morning, thinner towards noon, and thicker again at
night \*.

Mists and dew will, generally speaking, be the greatest when the difference between the heat of the air, in the day time, and at night, is the greatest, because the hotter the day, the greater is the quantity of water which is dissolved, and the colder the night, the greater will be the

<sup>\*</sup> Novi Commen. Petrop. Tom. vi. p.429.

the quantity which is precipitated. It often happens that there is no mist observable towards the close of the day, this may be occasioned, either by there being little difference in the heat of the air at noon, and at night; or, though that difference be confiderable, yet the air may chance not to be faturated with water, and in that case it may, even in the night, be warm enough to retain all the water it had diffolved in the day time. In cold weather the breath of animals becomes visible, because the air is not warm enough to diffolve the moisture which is exhaled from the lungs \*.

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<sup>\*</sup> The breath is visible if the temperature of the air be colder than 61 degrees. Caval. on air. p. 400. The degree of cold in which it is visible, depends partly on the humidity, or dryness of the air.

It is not unufual for a river in winter time, to be much warmer than the air, hence, the vapour which rifes from the river is condenfed, the air not being able to dissolve it, and a cloud or mist of a small elevation, is seen to accompany the river in its course; this appearance ceases, as soon as the river is frozen, because the ice, though it be subject to evaporation, yet it does not yield so much vapour as water does\*.

A cubic inch of rock falt, nitre, or any other kind of falt, is much longer in being dissolved, when it is in a compact state, than when it is reduced into a fine powder, because the falt, when in the form of a pow-

der,

<sup>\*</sup> Angara fluvius nocte glacie consistit, quo facto nebula illa perpetua, huc usque ex fluvio hoc evecta cessavit. Novi Com. Petrop. Vol. VI. p. 436.

der, has a much larger furface exposed to the action of the water, than if it was in one folid lump. In like manner, the air will dissolve any definite quantity of water fooner, when the furface of the water is increased by its being in the form of a vapour, than it would do if the water was either in the form of ice, or in its ordinary fluid state. The smoke of a chimney consists principally of water, in the state of vapour, and it is really aftonishing, to see how quickly, in particular states of the atmosphere, it is dissolved in the air.

It has been remarked, that the smoke of mount Vesuvius is much more strong and visible in rainy, than in fair weather\*; if this phe-

F 2 nomenon

<sup>\*</sup>Lett. sur La Miner: l. par M. Ferber. . p. 138.

nomenon does not proceed, from the greater quantity of water, which is raised from the mountain in wet, than in dry weather; it may be accounted for, from the greater facility with which aqueous vapours are dissolved in a dry serene air, than in one which is so saturated with water, that it can dissolve no more; which is the case, in general, of air which parts with its water, in the form of rain or mist.

In riding upon wet fand in a hot day, a kind of tremulous motion in the air, to the height of a foot or more above the fand, may be observed; this appearance may proceed from hence, that the water in rising from the fand, is not immediately disfolved in the air. A similar appearance may often be observed on land, in especial contents of the similar appearance may often be observed on land, in the similar appearance may often be observed on land,

especially in corn fields towards autumn; the water which is exhaled from the standing corn, not mixing itself at once, so esfectually with the air, as to constitute with it an apparently homogeneous sluid. Something of the same kind happens, when either saline solutions, wines, or vinous spirits of any kind, are poured into a glass of water, the compound sluid must be agitated, or, the mixture will not at first be uniform.

The quantity of water contained in the air, even in the driest weather, is very considerable. We may be said to walk in an ocean; the water indeed of this ocean, does not ordinarily become the object of our senses, we cannot see it, nor, whilst it continues dissolved in the air, do

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we feel that it wets us, but it is still water, though it be neither tangible nor visible; just as sugar, when dissolved in water, is still sugar, though we can neither see it, nor feel it.

Some philosophers have doubted, whether the weight of the air, may not chiefly be attributed to the water which is constantly suspended in it \*. But whether this conjecture be admitted or not, the power which the air has of keeping a great quantity of water dissolved in it, may very properly be applied to the illustration of that text, in which it is faid, God divided the waters which were under the firmament, from the waters which were above the firmament +, without having recourse with Episcopius

<sup>\*</sup> Boerh. Chem. Vol. I. p. 461.

den. i. 7.

copius, to the very unphilosophical supposition of the blue sky being a solid substance composed of congealed water \*. Some are puzzled to find water enough to form an universal deluge, to assist their endeavours it may be remarked, that was it all precipitated which is dissolved in the air, it might probably be sufficient to cover the surface of the whole earth, to the depth of above thirty seet.

The air not only diffolves water, but various other vapours, which con-

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\* Extima five suprema hujus aëris regio attingit fornicem illum cæruleum, in quo postea die quarta stellæ sixæ collocatæ suerunt; qui fornix cæruleus mihi esse videtur aquarum in altum elevatarum, et crystalli in morem seu condensatarum, seu conglaciatarum, cæruleoque colore radiantium, compages. Epis. Ins. Theol. Lib. iv. c. 3.

fift partly of water, and partly of volatile falts and oils. All vegetables, whether aromatic or not, are found to perspire very greatly, and the matter which they perspire, could it be condensed, would, probably, be so far different from pure water, as to have both a tafte and fmell. The matter perfpired by animals, without sweating, confifts principally of water, but the water is strongly impregnated with odorous particles. It has been faid of Baron Haller, that he could smell the perspiration of old people, at the distance of ten yards; this is by no means incredible, for the human body is constantly enveloped in an invisible cloud, arising from the great quantity of matter which is insensibly perspired. Sanctorius estimates the sensible excretions of a person person who eats and drinks 8 lbs of food in 24 hours, at 3 lbs, and the insensible perspiration at 5 lbs; but if we suppose the insensible perspiration in this climate (which is colder than that of Venice, where he made his experiments) to amount only to one half of our food, we cannot but conclude, that it must form a great cloud around us; for 4 lbs of matter converted into a vapour as heavy as air, would occupy a great space, amounting to above 50 cubic feet. The heat of the human body is generally between 90 and 100 degrees, this degree of heat is sufficient to raise from it, by a kind of distillation, a copious vapour, which would become visible, if the heat was increased; I remember having been greatly heated and fatigued in afcending cending the ladders from the bottom of the copper mine at *Ecton*; when I got to the top I observed, by the light of a candle, a thick vapour reeking from the body, and visible around it, to the distance of a foot or more.

The disposition of the air for disfolving either pure water, or the matter perspired by vegetables, or animals, is very various, depending chiefly on its density, heat, and dryness. The power which dogs have of fcenting the animal they are in pursuit of, must be much affected by this disposition of the air; for the air through which the animal has passed, is impregnated with the matter perspired from its body; and this matter may in one state of the air be so speedily dissolved, and so much

much as it were diluted with air, as to make either no impression, or a very slight one on the olfactory nerves of the dog; whilst in another, it may make a very sensible one. And if we suppose the perspirable matter not to consist chiefly of water\*, but of such particles as are thrown off by persumes, without their losing sensibly of their weight, still it will be true, that the state of the air must have a great influence

\* If the whole body of a naked man, except his mouth and nostrils, was shut up in a glass case, so that no air could enter, the matter of the insensible perspiration, would, probably, be condensed, and stand as dew on the inside of the glass; and I apprehend it would not differ much from the matter of the sensible perspiration, or sweat. But if any one be disposed to consider the insensible perspiration, as an incondensable shuid, or a kind

in rendering them sensible; since it has been found, that on the tops of very high mountains, where the state of the air is very different from what it is in the valleys below, the most odorous bodies lose either intirely, or in a great degree, their powers of exciting a smell. — The existence of water in air is made apparent various ways.

If a bottle of wine be fetched out of a cool cellar, in the hottest and driest day in summer, its surface will presently be covered with a thick vapour, which, when tasted, appears

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kind of air similar to that which arises from vegetable fluids, in a state of fermentation, (the heat of fermenting wort, being much the same as that of an animal body) still its mixture with the atmospherical air, must depend very much on the weight, humidity and other properties of that air.

to be pure water. This watery vapour cannot proceed from any exudation of the wine, through the pores of the bottle, for glass is impervious to water, and the bottle remains full, and when wiped dry, it is found to weigh as much as when taken out of the cellar. The fame appearance is observable on the outside of a silver, or other vesfel, in which iced water is put in fummer time; and it is certain, that the water which is condensed on the furface of the veffel, does not proceed merely from the moisture exhaled by the breathing of the people in the room, where this appearance is most generally noticed, because the same effect will take place, if the vessel be put in the open air. Water which is cooled by the folution

tion of any falt, or even spring water, which happens to be a few degrees colder than the air, produces a fimilar condensation of vapour on the outfide of the veffel in which it is contained. These and other appearances of the same kind, are to be explained on the same principle. Warm air is able to retain more water in folution than cold air can; when therefore warm air becomes contiguous to the outward furface of a vessel, containing cold liquor, it is prefently cooled to a certain degree, and in being cooled, it is forced to part with some of the water which it had dissolved, and this water, ceasing to be suspended by the air, attaches itself to the surface of the cold vessel.

The more ancient philosophers,

not fuspecting that water might be diffolved in air, were of opinion that the moisture which they observed adhering to the outfides of veffels, which had been cooled by having fnow put into them, proceeded from a transmutation of air into water\*. But there feems to be no more reafon for this supposition, than there would be for faying, that water was changed into faltpetre, from observing that water which had diffolved as much faltpetre as it could, in a certain

\* Naturæ mystas arcano modo, sed facili aërem in aquam mediis caloribus cogere docebit abjecta hæc nix, si vitro conicæ siguræ, intra tripodem, apice deorsum vergente, suspenso indatur nivis vel glaciei frustum. Quippe subjecto vasculo excipiuntur, exteriore vitri frigiditate collectæ, et laterum declivitate manantes aquæ guttæ. Bartholinus de sigura Nivis p. 3. See also Boyle's Works, Vol. II. p. 297.

certain degree of heat, deposited a part of it, when that degree of heat was lessened.

Another method of proving the existence of water in the clearest air, is, to observe the increase of weight, which certain bodies acquire by exposure to the open air. I put upon a plate 8 ounces of falt of tartar, which had been well dried on a hot iron; the day was without a cloud, and the barometer stood at 30 inches; - in the space of three hours, from 11 to 2 o'clock in the afternoon, the falt had increased in weight two ounces; in the course of a few days its weight was increased twenty ounces, it was then quite fluid, and being distilled it yielded a pure water equal in weight nearly to the increase it had acquired from the air, and

and therefore it is rightly inferred, that water was the substance which it had attracted from the air.

Strong acid of vitriol is another body which very powerfully attracts humidity from the air. An ounce of this acid has been observed to gain, in 12 months, above fix times its own weight \*. The power of the acid to attract water from the air, depends upon its strength, for it may be fo far diluted, that instead of attracting any more water from the air, it will, by evaporation, lose a part of that which it had acquired; when it is in this state, its weight varies with the dryness or moistness of the atmosphere, and it becomes; when accurately balanced in a good pair of scales, no bad kind of an hy-VOL. III. G grometer.

<sup>\*</sup> Newm. Chem. by Lewis, p. 161.

grometer. The time in which any definite quantity of acid acquires its greatest weight from the air, depends partly upon the quantity of water which is diffolved in the air, and partly upon the furface of the acid which is exposed to the air, it having been ascertained by experiment, that the quantity attracted from the air, in a definite portion of time, is greater as the furface is greater. Hence, instead of a twelve months exposure to the air, being requisite to make one ounce of acid of vitriol acquire fix ounces of water, it might possibly acquire that weight in a few minutes, if its furface was enlarged in a due proportion.

Onions and other bulbous roots, when hung up in a room sheltered from rain and dew, are observed to

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germinate and to acquire a great increase of bulk, and it might thence have been suspected, that they attracted much water from the air, and were increased in weight. But though they may increase in bulk, they are found to decrease in weight; the root itself in becoming rotten, fupplies nutriment to the germinating plant; and if it imbibes any thing from the air, it loses that and more by perspiration. An onion on the 26th of January, when it had scarce begun to shew any figns of vegetation, weighed 296 grains; on the 16th of the following May, after having put forth several stems in the open air, it weighed only 145 grains\*.

The increase of weight which the G 2 human

<sup>\*</sup> Novi Com. Petrop. Tom 2. p. 225.

human body, in many cases, experiences from the water which the pores of the body fuck in from the air, is another very fensible proof of the great quantity of water which is constantly dissolved in the air. "Keil has proved, that a young man weakened from want of nourishment, but in other respects healthy, added eighteen ounces to his weight, in the space of one night, and this by the absorption through his pores. Another person has been feen to gain 40 lbs weight, in the fame manner, in the space of a day. M. de Haen, is of opinion, that dropfical patients absorb more than 100 lbs weight every day. It is supposed, that in general, the body absorbs more than I lb every day by by the pores"\*. The skin of a middle sized man, is equal to about 15 square feet, and if we suppose the skin of a dropsical person to be 20 square feet, then will each square foot imbibe 5 lbs or pints of water in one day.

In addition to these instances Is will subjoin the following account, which was given me by a person of credit and judgment. A lad at Newmarket, a few years ago, having been almost starved, in order that he might be reduced to a proper weight for riding a match, was weighed at 9 o'clock in the morning, and again at 10, and he was found to have gained near 30 ounces in weight in the course of an hour, though he

<sup>\*</sup> Treatise of Physic by Zimmerman... Vol. II. p. 128.

had only drank half a glass of wine in the interval. The wine probably stimulated the action of the nervous fystem, and incited nature, exhausted by abstinence, to open the absorbent pores of the whole body, in order to fuck in some nourishment from the air. Something similar to this was the case of the negro, who, being gibbetted alive, regularly voided every morning a large quantity of urine, but discharged no more till about the same hour the next day\*. The dews of the evening at Charles Town in South Carolina, imbibed by his body, fupplying a superabundance of fluids in the night, and a fufficient quantity to support perspiration in the day. It has been observed that "neither hogs

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<sup>\*</sup> Medical Trans. Vol. H. p. 103.

nor beafts of burden ever drink in Jamaica, and yet they are continually fweating. The air is fo moift, that the absorbing pores of these animals imbibe a fufficiency of water\*. The imbibition of water through the pores of the skin is an acknowledged fact - "it is well known, that perfons who go into a warm bath, come out feveral ounces heavier than they went in; their bodies having imbibed a correspondent quantity of water+. Part of the utility of medicated and vapour baths, depends upon this principle of imbibition by the pores: and it is faid, that thirst may be allayed by bathing in warm fea water, the pores

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<sup>\*</sup> Treatise of Phys. Vol. II. p. 101.

<sup>+</sup> Goldfmith's Hift. of the Earth. Vol. I. p. 238. — 398.

imbibing the water and carrying it to the intestines, but not suffering the dissolved falt to accompany the water.

With respect to the quantity of water suspended in the whole atmosphere, or even in a column of the atmosphere, of a definite basis, incumbent on any particular spot, it cannot be ascertained with precision, unless we knew some method of depriving the air of all the water it contains, and could at the same time make the experiment at different distances from the surface of the earth. For it is not only probable, that a cubic yard of air, contiguous to the furface of the earth, contains at different times very different quantities of water, even at the same place, according as the ground is maist

moist or dry, or the temperature of the weather warm or cold; but we have great reason to believe, that at the same instant of time, a cubic yard of air which touches the surface of the earth, contains as much water as three or four cubic yards, which are situated at the distance of thirty or forty yards above it. For the water which rifes from the furface of the ocean, from the perspiration of organized bodies, whether vegetable or animal, or from the mere action of the fun on a moist earth, in being dissolved in the air as foon as it rifes, makes the air near the furface, heavier than that which is at a distance from it, and on that account the motion of the air, unless it be violent, will not readily mix the lower and heavier air, with the higher

higher and lighter, and the lower air will consequently contain more water in a definite bulk, than the higher. To what has in a former Essay been observed on this subject, the following illustration may be added. It into a deep drinking glass half full of water, you gently pour a glass of port or claret, you will fee the wine mixing indeed itself slowly with the water, but that part of it which is near the water, will be much more impregnated, in any definite portion of time, with water, than the more remote parts; it will be a confiderable time before the water will be uniformly diffused through the wine, if they are left undisturbed; nor does a gentle undulating motion foon mix them, and this difficulty of mixing them, would be still much greater,

greater, if there was a greater difference in their respective weights, or if the upper parts of the wine were less dense than the lower. Now this is the case in the air, which is not only above 800 times lighter than water, but its parts, which are far removed from the furface, are much less dense than those which are contiguous to it. That dense air holds more water in folution than rarefied air, is proved from hence; that when common air is rarefied under the receiver of an air pump, a part of the water which it contained is precipitated, in the form of dew; this answers to the precipitation of falt from a faline folution, when part of the water is taken away, which held the falt in folution. Hence, as cold tends to render the air more dense,

it certainly contributes to its holding more water in folution than it would do, if it was more rarefied under thefame degree of heat: but as hot air dissolves more water than cold air, and as air is rarefied by heat, it is evident, that the density and heat of the atmosphere in some measure counteract each other, with respect to the power the air has of dissolving water: the law according to which this power varies, in different degrees of heat and condensation, is not determinable from any experiments which have yet been made.

It may not be improper to take notice in this place, of an objection which is usually made to the doctrine here advanced, — of water being suspended in the air by solution — It is afferted, that water is as evapor-

able in an exhausted receiver, where there is no air, as in the open air \*. It is certain, that heat will evaporate water, and great degrees of it may, probably, evaporate it faster in vacuo, than in the open air, inasmuch, as the pressure of the air may tend to obstruct the action of the heat, in converting the water into vapour. Thus, quickfilver is not, I apprehend, evaporable in the open air, yet it has long been remarked to be evaporable in vacuo, as may be collected from the little globules of quickfilver, generally found adhering to the upper part of a barometer, and which arise from the vapour which infenfibly escapes from the furface of the quickfilver in the tuhe.

<sup>\*</sup> Berlin Mem. 1746. Waller de ascen. vapo. in vacuo.

tube. But though heat may be one cause of the evaporation of water, the attraction between air and water, upon whatever principle it depends, may be another. The fact moreover, upon which the objection is founded, is very questionable, and not generally to be admitted. A china faucer which contained 3 ounces of water, lost nothing of its weight under an exhausted receiver in the space of 4 hours; whilst a similar faucer, containing an equal quantity of water, loft, in the fame time, in the open air, one drachm and eight grains, the heat of the atmosphere being between 48 and 50 degrees\*.

Many readers are gratified with feeing the general progress of any philo-

<sup>\*</sup> See Dr. Dobson's ingenious Observations in Philos. Trans. 1777. p. 256.

philosophical opinion, from its being first suggested, till its being generally admitted. The history, indeed, of philosophy, is one of the most pleasing pursuits which a speculative mind can be engaged in, but it requires great leifure and ability to cultivate it with fuccess. It is not every distant hint which he throws out, that can intitle a philosopher to the credit of being the first framer of an hypothesis; nor on the other hand are we hastily to reject the maxim that "all novelty is but oblivion", inafmuch as we frequently fee old opinions putting on the appearance of new discoveries, from their being dreffed out in a new form.

Natural philosophy principally consists in exploring by experiment, the

the phenomena refulting from the mutual action of different bodies upon each other. These phenomena are innumerable, no arithmetic can reckon up the various ways in which terrestrial bodies may, by natural or artificial means, be brought to operate on one another. To this cause may we attribute the immense number of volumes on experimental philosophy, which have been published in Europe fince Bacon pointed out the proper method of studying nature. This circumstance, joined to the uniformity which must ever attend the operations of nature in fimilar circumstances, may justly intitle different men to the honour of having made the fame discoveries, it being much easier to make an experiment, which may have been made

made before, than to read all that has been written in different ages and countries on natural appearances.

Doctor Halley in the year 1691, proposed to the Royal Society, his opinion concerning the origin of springs: in this tract he expresses himself in the following manner, "the air of itself would imbibe a certain quantity of aqueous vapours, and retain them like falts dissolved in water, the fun warming the air, and raising a more plentiful vapour from the water in the day time, the air would fustain a greater portion of vapour, as warm water would hold more diffolved falts, which upon the absence of the sun, in the nights, would be all again discharged in H VOL. III. dews.

dews, analagous to the precipitation of falts on the cooling of liquors." \*

M. Le Roy published an ingenious differtation on the folubility of water in air, in the year 1751; among other experiments, by which he illustrated his hypothesis, he observes that if a large new, hollow, globular glass vessel, with a narrow neck, be closely corked up in a clear hot day, the water contained, in the apparently dry air, will be precipitated, and form a dew in the infide of the veffel, whenever the vessel is cooled, and that this dew will vanish, being redissolved by the air included in the vessel, as soon as the air regains its heat.

Doctor Franklin further illustrated this principle, of water being foluble

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<sup>\*</sup> Philos. Trans. No. 192.

fore the Royal Society in 1756, and afterwards printed in his works \*.

In the French Encyclopedie, published in 1756, we meet with the following passage - on voit par la combien se trompent ceux qui s' imaginent que l'humidite qu'on voit s'attacher autour d'un verre plein d'une liqueur glacee est une vapeur condensee par le froid: cet effet, de meme que celui de la formation des nuages de la pluie, et de tous les meteors aqueux, est une vraie precipitation chimique, par un degre de froid qui rend l'air incapable de tenir en dissolution toute l'eau dont il s'etoit charge par l'evaporation dans un tems plus chaud; et cette precipitation est precisement du me-

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<sup>\*</sup> Franklin on Elec. p. 182.

me genre que celle de la creme de tartre, lorsque l'eau qui la tenoit en dissolution s'est refroidie.\*

Muschenbroek, amongst other causes which he assigns for the suspension of vapour, evidently alludes to the solution of water in air, and compares it to the solution of salts in water †.

But though a great many philofophers had spoken of the solubility of water in air, before *Doctor Hamil*ton, yet in justice to him it must be owned, that no one has treated the subject more distinctly, or applied it more successfully to the explanation of various phenomena than he has done, in an essay which was read to

<sup>\*</sup> Ency. Fran. T. 6. p. 283. Fol. Ed.

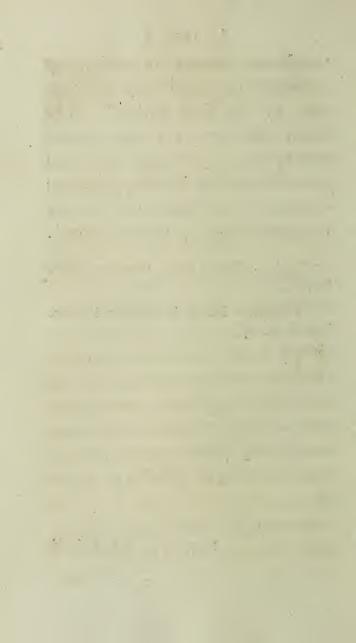
<sup>†</sup> Introd. ad Phil. Nat. Vol. II. p. 965, pub. 1769.

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the Royal Society in 1765, and afterwards published with other effays, by the same author\*. The Reader will be very well pleased with seeing this principle illustrated in an essay by Mr. White, published in 1771, in the elegant collection of Georgical Essays by Dostor Hunter +.

<sup>\*</sup> Philo. Essays by Hugh Hamilton, D.D. F. R. S.

<sup>†</sup> Georgical Essays by Doctor Hunter. Vol. II. p. 15.





## E S S A Y IV.

Of Cold produced during the Evaporation of Water, and the Solution of Salts.

N the 27th of March 1779, when the weather had been for some time very dry, I put a thermometer into a glass of water, which had been heated to 87 degrees, by standing exposed to the direct rays of the sun. The thermometer was then taken out, and its bulb was held opposite to the sun which shone very H 4.

bright; as the bulb grew dry by the evaporation of the water, the mercury in the thermometer funk very fast; it continued for a moment stationary at 76 degrees, and then it rose rapidly to 90; so that 11 degrees of cold had been produced during the evaporation of the water.

On another day in the same month, when the heat in the shade was 68 degrees, I put a thermometer into a glass of water, it stood at 50 degrees; upon taking it out, the mercury instead of sinking from the effect of evaporation, began immediately to rise from the effect of the heat of the atmosphere upon it. I put the thermometer into the same water, heated to 55 degrees, and taking it out, the mercury continued stationary for some time, and afterwards it began

to rise. It was put into the samewater, heated to 58 degrees, and upon being taken out, the mercury did not either rise or continue stationary, but it funk one degree; when the water was heated to 60 degrees, the thermometer upon being taken out, funk 3 degrees before it began to These experiments were all made in the shade, and it seems as if we might conclude from them, that 57 was the degree of heat in the water, in which the cold produced by evaporation, was just equal to the heat produced by the atmosphere which then furrounded the ball of the thermometer.

The degree of cold produced by evaporation, depends, probably, upon the quickness with which that is accomplished: now the quickness

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with which water, of a definite temperature, is evaporated, is influenced, partly by the degree of heat prevailing in the atmosphere; partly by the wind blowing upon the thermometer; partly by the dryness or moistness of the air; and by other causes.

September 30th of the same year when the heat in the shade was 64 degrees, and the heat of the water 60, the thermometer upon being taken out, stood stationary for three minutes, and then it rose; there was a gentle south wind. On the next day there was a cold dry wind from the north, the water and air were both at 56 degrees, and the thermometer on being taken out sunk to 52.

Spirits of wine, ether, and many other fluids, produce cold by being

evaporated, and they produce a much greater degree of cold than water, in consequence, probably, of their being more evaporable. Thus, vitriolic ether\*, which is one of the most volatile fluids in nature, has been observed to lower Reaumur's thermometer 40 degrees below the freezing point, (which answers to 90 degrees of Fahrenheit's scale +. The experiment is most commodiously made, by applying a piece of fine linen wetted with ether upon the bulb of the thermometer, accelerating

<sup>\*</sup> Ether is made by distilling a mixture of spirits of wine and oil of vitriol. — Ether may be made also by distilling spirits of wine with the several acids of nitre, sea salt, and vinegar, and it is then called the nitrous, marine, acetous ether.

r Chem. Dict. art. Ether. Or, Manuel de Chymie. par M. Baumé, p. 375.

ing the evaporation by blowing on the linen with a bellows, and moistening the linen as it becomes dry, or exchanging it for a fresh piece which is wetted with ether. Whoever attempts to ascertain the degrees of cold respectively produced by different fluids, would do well to remark particularly the state of the atmosphere with respect to other circumstances, as well as to its heat.

Sailors have a custom, in a calm, to hold a wet finger up into the air, and if one side of it, in drying, becomes colder than another, they expect wind from that quarter. This custom is not without its foundation; for an almost insensible motion of the air, will evaporate the water from one side of the singer sooner.

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than from another, and thus produce a degree of cold.

There is a fimilar experiment, by which any one may convince himself that cold is produced by evaporation; let him wet a finger by putting it in his mouth, and then hold it up in the air, even in a warm room where there is no current of air, he will find that it grows cold as it becomes dry by the evaporation of the humidity.

"The method our gentlemen make use of to cool their liquors, is to wrap a wet cloth round the bottle and set it in the land wind: and, what is very remarkable, it will cool much sooner by being exposed thus to this burning wind, than if you take the same method, and set it in

is produced by the evaporation of the water from the wet cloth, and as the hot land-wind will evaporate the water fooner than the cold fea-breeze, it is not to be wondered at, that the liquor is fooner cooled when placed in the former wind than in the latter.

"Kempfer relates, that the winds are so scorching on the borders of the Persian gulph, that travellers are suddenly suffocated, unless they cover their heads with a wet cloth; but if this be too wet, they immediately feel an intolerable cold, which would become fatal to them if the moisture were not speedily dissipated by the heat." ‡ The cold, which is

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<sup>\*</sup> Ives's Voy. p. 77.

<sup>†</sup> Treatise of Physic by Zimmerman, Vol. H. p. 151.

produced by the act of evaporation, ceases as soon as that is finished, by the cloth becoming dry.

The manner of making ice, in the East Indies, has an evident dependence on the principle of producing cold by evaporation here mentioned. On large open plains the ice-makers dig pits about 30 feet square and 2 deep; they strew the bottoms of these pits, about eight inches or a foot thick, with sugar canes, or with the dried stems of Indian corn. Upon this bed they place a number of unglazed pans, which are made of fo porous an earth, that the water penetrates through their whole fubstance. These pans, which are about a quarter of an inch thick, and an inch and a quarter deep, are filled, towards the dusk of the even-

ing in the winter feafon, with water which has been boiled, and then left in that fituation till the morning, when more or less ice is found in them, according to the temperature of the weather; there being more formed in dry and warm weather, than in that which is cloudy, though it may chance to be colder to the feel of the human body.\* Every thing in this process is calculated to produce cold by evaporation, the bed on which the pans are placed, suffers the air to have a free passage to their bottoms, and the pans, in conflantly oozing out water to their external furface, will be cooled in consequence of that water being evaporated by a gentle stream of warm dry air, the power of the

<sup>\*</sup> Philos. Trans. for 1775, p. 252.

the air to evaporate water depending much upon its warmth and dryness.

They have a kind of earthen jar in some parts of Spain, called Buxaros, which are only half baked, and the earth of which is so porous, that the outside is kept moist by the water filtering through; though placed in the sun, the water in the pots remains as cold as ice:\* and it probably is colder from the jar being placed in the sun, because the evaporation is thereby increased.

The Blacks at Senegambia have a fimilar method of cooling water. "They fill tanned leather bags with it, and hang them up in the fun; the water oozes more or less through the leather, so as to keep the outward surface of it wet, which, by its quick

<sup>\*</sup> Swinburne's Trav. p. 305.

quick and continued evaporation, occasions the water within the bag to grow considerably cool."+

It is common enough for labouring people, in the height of summer, to drink feveral quarts of beer or other beverage in a day; this quantity is principally discharged from the body by perspiration; and the cold which is generated during the evaporation of the fweat, greatly contributes to keep the body cool. Thus has Providence contrived to render the heat of the torrid zone less insupportable to the inhabitants; an intense heat bathes the body in fweat, but the fweat being evaporated by the same heat which occasioned it, a degree of cold is generated on the

<sup>†</sup> Philof. Trans. 1780. p. 486.

the furface of the body, which would not otherwise have been produced.

It feems reasonable to attribute the cold, which is produced in these and other similar circumstances, to the evaporation of the water, rather than to any other cause; because when the bulb of a thermometer is wetted with different fluids, the cold produced has a manifest dependance on the evaporability of the fluid with which it is wetted. Thus, more cold is produced when the thermometer is wetted with spirits of wine, than when it is wetted with water, because spirits of wine are more evaporable than water; and more is produced when it is wetted with ether, than with spirits of wine, because ether is more evaporable than spirits of wine. No cold is pro-

duced

duced when the thermometer is fmeared with linfeed oil, or other oils of a similar nature, because these oils are not fenfibly evaporable in the ordinary heat of the atmosphere. Strong acid of vitriol when exposed to the air, instead of losing any thing of its weight, acquires an increase, by attracting the humidity of the atmosphere; and as strong acid of vitriol when mixed with water, generates a degree of heat, so the bulb of the thermometer, when wetted with strong acid of vitriol, instead of being cooled, is warmed, and the mercury ascends, in consequence of the heat produced from the union of the acid of vitriol with the water contained in the air.

When water is refolved into vapour, by the violence of a fall from

a considerable height, the air will diffolve it fooner; and in diffolving it fooner, it will, probably, produce more cold than it would have done, if the surface of the water had not been broken; hence natural and artificial cascades, may, probably, be serviceable in cooling the air furrounding them. This observation is purposely expressed in diffident terms, because, having more than once sprinkled the floor and fides of a room with water in the fummer time, when the heat of the air in the room and of the water was 68 degrees, I could not observe that a thermometer hung in the middle of the room, changed its degree of heat whilst the room grew dry. In very hot climates the effect may, probably, be different; thus we are told, that in the I 3

the island of St. Lewis, in the river Senegal, "water poured on the floor of a room for the purpose of cooling the air, is dried up in an instant, and there is fome effect on the thermometer placed in such a room."\*

This phenomenon of producing cold by evaporation, had been mentioned by M. Amontons in the year 1699.† It had been noticed also by M. Mairan in 1749,‡ and by Mussichenbroek, in his Essai de Physique. Professor Richman, at Petersburgh, gave an account of several experiments, which he had made on this subject in 1747 and 1748, || but he did

<sup>\*</sup> Philos. Trans. 1780. p. 485.

<sup>†</sup> Mem. de l'Acad des Scien. a Paris, 1699.

<sup>†</sup> Dissertation sur le Glace.

<sup>||</sup> Novi Comment. Petrop. Tom. I. for 1747 and 1748.

did not explain the finking of the mercury in the thermometer, whilst its bulb grew dry, on the principle of evaporation. Dr. Cullen has very particularly illustrated this principle, in a paper published in 1756; and he has there shewn that the cold produced was greater, when the evaporation was made in vacuo, than in the open air.\* Lastly, Professo: Braun, to whom the world is indebted for the discovery of freezing quickfilver, has made a further investigation of this matter, by publishing a table of the degrees of cold produced during the evaporation of different fluids. +

During the folution of falts in water

<sup>\*</sup> Essays, Physical and Literary, Vol. II. Edinb. 1756. p. 145.

<sup>†</sup> Novi Commen. Petrop. Tom. X. 1764.

ter either cold or heat is generally produced, but more commonly cold. Fixed alkaline falts, Glauber's falt, and white vitriol produce small degrees of heat during their solution. Sal ammoniac produces the greatest degree of cold, of any falt hitherto known.

When Fahrenheit's thermometer stood at 68 degrees, both in the open air, and in the water which was used for the experiments, I saturated equal portions of water with sal ammoniac, with saltpetre, and with sea salt. The sal ammoniac made the mercury sink from 68 to 42 degrees, hence, 26 degrees of cold were produced; the nitre produced 17 degrees, and the sea salt produced only 2 degrees of cold. I repeated the experiment with the sea salt seve-

ral times, and with different forts of it, but I could never observe that it produced above 2, or at most 2 1 degrees of cold. The experiments with fal ammoniac and faltpetre, agree very well with those made by M. Eller, and mentioned in the Berlin memoires for 1750; fince he produced almost 27 degrees with fal ammoniac, and 18 with faltpetre. Boerhaave, indeed, made the thermometer descend through 28 degrees by diffolving fal ammoniac in water; but he had reduced his falt to a very fine powder, and dried it well before he used it; and a difference in the fineness of the powder to which the falts are reduced before they are dissolved, may make a difference of a degree or two in the cold produced; for the finer the falt, the the more surface has the water to act upon, and the quicker will the solution be performed; and as the cold is produced only by the act of solution, the sooner that is accomplished, the less effect will the heat of the atmosphere have, in restoring to the water, during the time of the solution, any part of the heat it may have been deprived of, during the immediate action of the water upon the salt.

Does any given kind of falt, during its folution in water, produce the fame number of degrees of cold, whatever be the temperature of the water before folution? I have only endeavoured to refolve this question with respect to fal ammoniac, and it feems to me that the quantity of cold produced, is not influenced by the

temperature of the water. In the fummer season when the temperature of the air, water, and fal ammoniac were each of them 70 degrees, the water fank during the folution, of as much fal ammoniac as would faturate it, to 44 degrees, or through 26 degrees. I thawed fome fnow in winter, the thermometer stood in the fnow water at the freezing point, or at 32 degrees; by putting fal ammoniac, which was equally cold, into the water, the thermometer descended during folution to fix degrees, or through 26 degrees.

The possibility of freezing water in the middle of summer, is rightly enough inferred from this experiment. In a tub, suppose of 3 feet in diameter, place a bucket, a little taller than the tub, of 1 foot in dia-

meter; in the bucket hang a florence flask, or a flat lavender water bottle, so that the mouth of the bottle may be above the rim of the bucket: fill these vessels with water heated, suppose, to 70 degrees. Saturate the water in the tub with fal ammoniac, then will the 70 degrees of heat be reduced to 44, the water losing, during the folution of the falt, 26 degrees. The water in the bucket being furrounded with this cold fluid, will itself be cooled; suppose it to be cooled only to 50 degrees, then by faturating it with fal ammoniac, it will lose 26 degrees more of its heat, and be cooled to 24 degrees. The water in the bottle, being immersed in a fluid, heated only to 24 degrees, will foon be cooled below the the freezing point or 32 degrees, and consequently will concrete into ice.

The cold, in all these cases, is generated only during the time of the folution. The water recovers the temperature of the atmosphere sooner or later, according as its quantity is less or greater, and as the surface exposed to the air is greater or less; it is here supposed, that the heat of the atmosphere remains the same. The different degrees of cold produced by different falts, do not depend upon any general cause which has yet been discovered, nor is there any very fatisfactory reason given for these, and other similar productions of cold or heat. The time may come when we shall be able to comprehend the reason why the acid of nitre has fuch different effects when mixed mixed with snow, from what it has when mixed with snow water; when mixed with snow water it excites a very great degree of heat; and when mixed with snow it produces the greatest degree of cold that has ever yet been observed\*. Rerum natura, sacra sua non simul tradit. Initiatos nos credimus, in vestibulo ejus hæremus. Illa Arcana non promiscue nec omnibus patent; reducta et in inferiore sacrario clausa sunt. Ex quibus aliud hæc ætas, aliud quæ post nos subibit, adspiciet.

\* Vol. I. p. 267.

ESSAY



## ESSAY V.

Of the Degrees of Heat in which Water begins to part with its Air, and in which it boils.

THE air bubbles which, in fummer time, adhere to the infides of decanters, water glasses, and other vessels filled with water, cannot have escaped the observation of any one; I have endeavoured to ascertain the degree of heat in which these bubbles begin to be formed.

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Into

Into a water glass filled with water I immersed a thermometer, the heat of the water was 64 degrees; the water was fet in a closet, where the fun never shone, for two days; the heat remained much the same during that period, and there was no appearance of bubbles. The glass, with the immersed thermometer, was then fet in the fun, and when the heat amounted to about 90 degrees, several air bubbles were found adhering to the graduated fide of the thermometer, and fome were beginning to be formed on the bottom and fides of the glass.

Having frequently feen the infides of vessels containing water, studded with bubbles, when the heat, it was apprehended, was much less than 90 degrees; I put a thermome-

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ter into a water glass at a time when it abounded with bubbles, and found that the heat of the water was not above 64 degrees.

The result of this experiment being very different from that of the preceding, in which the air did not begin to separate itself from the water till the heat was about 90 degrees, I was for some time at a loss how to account for the difference: recollecting, however, that the water which required 90 degrees of hear before it parted with its air, was pumped from a well fed by a stream, which had run four miles in the open air; and that the other water, which let go its air at 64 degrees, was pumped from a well fed by subterraneous springs, I attributed the difference in the degree of heat K. VOL. III. requirequisite to make these waters part with their air, to the different qualities of the waters.

In order to try these waters under similar circumstances, two water glasses were filled, one with common well water, another with that which had been supplied by the stream; on being exposed to the air, bubbles began to be formed in the well water when the heat amounted to 60 degrees, the other did not part with any of its air in the same degree of heat.

I was at first disposed to think, that these experiments pointed out a general difference between river water and well water, with respect to their disposition for retaining or parting with their air; but the following experiment made at a different sea-

fon of the year, convinced me that the conjecture was not well founded.

In November, when the heat of the air had been for some time about 50 degrees, I took three water glasses; one was filled with rain water immediately after it had fallen, another with the common well water, the third with the water which came from the stream: the heat of these feveral waters was the fame, namely 48 degrees; they were all gradually warmed, by fetting the water glasses in hot water, and they all began to exhibit bubbles when the heat was about 60 degrees; I thought the rain. waters shewed the most bubbles.

Hence it is plain, that the stream water does not differ from rain or well water, except accidentally, as to the degree of heat in which it parts

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with its air. The first experiment, in which the bubbles were not formed till the heat was 90 degrees, was made after there had been several days of very hot weather, and the water in being exposed, during its course, to the action of the sun, had probably lost a considerable portion of its air before it arrived at the well. All river water has a vapid tafte in fummer time, which is in part, probably, occasioned by having lost some of its air, in consequence of its being exposed to the rays of the fun. Water drinkers are defirous of having water fresh from the well, especially in summer time, and not without reason, for the heat in that feafon being generally above 60 degrees at our principal meal time, the water, if it has been long exposed

change of quality, not only from its increase of heat, but from a consequent loss of a portion of its air. The water which supplies the warm bath at *Matlock*, and which is drunk by invalids, is 68 degrees warm; hence it has lost a part of the air which it would naturally contain, and except in very hot weather it does not exhibit any air bubbles in the decanters.

The air begins to be visibly separated when the heat is about 60 degrees; but it begins, probably, to be invisibly separated when the heat is much less: and the least heat will be requisite to separate it, when the weight of the atmosphere is the least.

Philosophers have invented various methods, equally conclusive, of

shewing, that water in its ordinary state, contains dissolved in it a portion of air. And they have shewn, that water which has loft a portion of this air, either by being frozen, or heated, or by long continued agitation, or by other means, has the property of re-absorbing as much air from the atmosphere as it had lost; and they have shewn, that this absorption is the strongest at first, and becomes eless and less powerful, as the water becomes more and more impregnated with air. These and similar observations render it probable, that water is as capable of dissolving a certain portion of air, as it is of dissolving a certain portion of any particular kind of falt. The quantity of air, which water is capable of dissolving and retaining in folution, depends partly upon

upon the temperature of the water, partly upon the weight of the atmosphere, and partly, I conceive, upon the water's purity. From these circumstances, as well as from some others which might be attended to in making the experiment, it has happened, that authors have given very different accounts of the quantity of air contained in water. Boerhaave has an experiment \*, from which he infers, that there may be feparated from water a quantity of air equal in bulk to the water; the experiment is ingeniously contrived, but the conclusion, I think, is liable to some objections. The Abbé Nollet fays, that water which has been previously purged of air, absorbs, in fix days, one thirtieth of its bulk. +

Doctor

<sup>\*</sup> Boerh. Chem. Vol. I. p. 521.

<sup>†</sup> Hist. de l' Acad. 1743.

Doctor Hales obtained by distillation one cubic inch of air from fifty-four cubic inches of water\*. Mr. Eller is of opinion, that the portion of air contained in water does not exceed the 150th part of its bulk +. Dr. Priestley found that a pint of his pump water contained about one fourth of an ounce measure of air, that is, the bulk of the water was to that of the air it contained, as 64 to III. M. Fontana fays, that the water of the Seine at Paris, after being long boiled, absorbs in forty days one twenty eighth of its bulk of common air t. Laftly, M. Cavallo observes, that in a temperate degree of heat, and when the barometer is about'

<sup>\*</sup> Veg. Stat. c. 6. + Berl. Mem. 1750.

<sup>||</sup> Philof. Tranf. 1772. p. 248.

<sup>1</sup> Philos. Trans. 1779. p. 439.

about 29½ inches, water absorbs about one fortieth of its bulk of common air\*.

It has been remarked in another place +, that the atmospherical air confifts, in part, of fixed air; and some of the most striking differences between fixed and atmospherical air were there mentioned. If a bubble of atmospherical air of a definite bulk, suppose it equal to eleven pints, be exposed to the action of a fufficient quantity of water, which has been purged of its air by boiling, the whole of the bubble will, in a proper length of time, be absorbed by the water; but when about feven pints, or even a less portion, have been absorbed, the remaining part

<sup>\*</sup> Cavallo on air. p. 213.

<sup>†</sup> Vol. 11. p. 247.

will refemble fixed air in this - that a candle will not burn in it\*. It is very probable that water which has not been boiled may have a fimilar effect under certain circumstances. - "The wells at Utrecht are from 8 to 20 feet in depth; it has been the custom to make use of pumps to raise the water, and they are then covered over with a kind of arch. When after a certain period of time, the wells are opened, on any account, it is necessary to leave them uncovered for 12 hours, before any person descends into them; whoever should venture to go down into them fooner, would expose himself to immediate death. The air of these wells extinguishes candles like that acquired from fermentation or effer-

<sup>\*</sup> Philos. Trans. 1772. p. 247.

effervescence". \* - Stagnating air, which has brooded, though but for a short time, even over running water, is found to be fo greatly altered in its quality, that it will extinguish flame, though it be fufficiently pure to support animal life. I was informed of this fact by a miner in Derbyshire, who had frequently verified it by his own experience. In order to free a mining district from water, they frequently dig for miles together fubterraneous aqueducts, fupporting the fides and roof with timber or stone. The mouths or outlets of these aqueducts or foughs, being below the level of the district to be drained, there is a constant stream of water flowing through them. These foughs are many of them

<sup>\*</sup> Lavoisier's Essays. p. 118.

them high enough for a man to walk upright in them, the water reaching to his middle or higher; and men with lighted candles frequently walk through them from one end to the other, in order to prevent obstructions; it sometimes however happens, that by the falling in of the roof, or other accidents, the fough is in part dammed up: when this is the case, the water beyond the place where the obstruction is, rises to the roof of the fough, and thus prevents a circulation of air, though there is still a discharge of water through the mouth of the fough. When an accident of this kind happens, men are fent with candles in their hands to find out and remove the obstruction, but before they have walked fifty yards from the mouth of the fough,

fough, the candles go out, though they perceive no difficulty in breathing, and this extinction of the candles will take place in 24 hours, after the stoppage of the water has commenced.

Fahrenheit, Boerhaave, and other philosophers had observed that the degree of hear, requisite to make water boil, was variable according to the purity of the water and the weight of the atmosphere. Within the usual limits of 28 and 31 inches in the barometer, Boerhaave was of opinion\*, that there would be a variation in the heat of boiling water. amounting to 8 or 9 degrees. This subject has of late been examined with great accuracy by Mr. de Luc, and Sir George Shuckburg; and Mr.

Cavallo

<sup>\*</sup> Chem. Vol. I. p. 171.

Cavallo has given us the result of their experiments in the annexed table, which is formed according to the scale of Fahrenheit's thermometer \*.

TABLE

	Heat of boiling water	
Height of the	according to	
Barometer.	Mr. de Luc	Sir G. Shuckburg
1 100 - 100	Parts of Deg. a deg.	Parts of a Deg. deg.
26	205,17	204,91
261	206,07	205,82
27	206,96	206,73
271/2	207,84	207,63
28	208,69	208,25
281	209,55	209,41
29	210,38	210,28
291	210,2	211,15
30	212	212
302	212,79	212,85
31	213,57	213,69

<sup>\*</sup> Caval. on air. p. 215.

The following experiment is curious in itself, and it illustrates both the nature of boiling in general, and what is here advanced relative to the heat of boiling water under different pressures of the atmosphere. I hit upon it many years ago, when I had another object in view. My defign was to exhibit a striking instance of the increase of dimensions produced in fluids by various degrees of heat: in order to this, I took a large glass vessel, resembling in shape, such mercurial thermometers as have a bulb at the bottom \*, the bulb of this vessel held above a gallon, and the stem had a small diameter, and was above two feet in length. Into this vessel I poured boiling

<sup>\*</sup> A vessel of this shape is usually called a Matrass.

boiling water, and having filled it up to the very top of the stem, I corked it with a common cork as close as I could. The water and the cork were at first contiguous to each other; but in a very little time the water began to grow cold, and as it grew cold, it contracted itself and funk very visibly in the stem; and thus the first intention of the experiment was fully answered. But an unexpected phenomenon presented itself, - the water, though it was removed from the fire, - was growing cold, - and had for some time entirely ceased from boiling, - began to boil afresh very violently, the bubbles were large and numerous, and continued to ascend, into the space between the surface of the water in the stem, and the cork, where they

they burst, for above two hours. When a hot iron was applied to that part of the stem, through which the water in contracting itself had defcended, the ebullition presently ceased; it was renewed when the iron was removed; and it became more than ordinarily violent, when by the application of a cloth dipped in cold water, that part was cooled. There is no great difficulty in accounting for these several appearances: by the finking of the water in the stem a kind of vacuum is left between its furface and the cork; water and other. fluids boil with less degrees of hear, when the pressure on their surface is diminished; here the pressure of the atmosphere is wholly removed by means of the cork, and the water continues to boil, though its heat be T. VOL. III. con-

constantly decreasing. The interval between the water and the cork is not, as will be shewn presently, a perfect vacuum; it is occupied either by the vapour of the water, or by a fmall portion of air, or by both; heat increases the elasticity of both air and vapour, and thus augments the pressure upon the surface of the water; hence, the ceasing of the ebullition on the application of the hot iron; cold diminishes the elasticity of air, and condenses vapour, and thus, the pressure upon the surface being lessened by the application of the cold cloth, the ebullition of the water became more violent. When the water ceased boiling I poured it on the bulb of a thermometer, and found that its heat was only 130 degrees.

Another

Another circumstance deserving of notice, remains to be mentioned. When the water was become cold, it had funk through the whole stem, and through part of the bulb, I then inverted the vessel which contained it, into a tub of water, and observed upon the bottom of the bulb a large circular spot void of water. I confidered this spot as a perfect vacuum, for it answered to the space which the water, in contracting itfelf, had deferted; and the vapour which, whilst the water was warm, might have been supposed to occupy that space, I was perfuaded, was condenfed by the cold: in order to fee whether it was a vacuum or not, I pulled out the cork, whilft it was under the furface of the water into which the vessel was inverted, being

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certain

certain that if it was a vacuum, it would be instantly filled with water, which the pressure of the atmosphere would make to afcend through the stem. In fact the circular spot was greatly diminished by the ascent of the water, but never (for the experiment was often repeated) taken wholly away: what remained must have contained either air, or fome other fluid, whose elasticity was a counterpoize to the pressure of the atmosphere, on the furface of the water in the tub. It would be too hasty a conclusion from this circumstance, to attribute the formation of the bubbles to the particles of air, from which water cannot be separated by long boiling \*; for it may be,

<sup>\*</sup> Licet diu ebullierit aqua non erit aëris expers. Muschen. de Aqua.

be, that this small portion of air arose from the substance of the cork, or from the air in the water of the tub, that water having not been boiled; or it may have been intangled in the parts of the boiling water, as it was poured into the vessel, and not have had time to escape before the cork was inserted; or, lastly, which is the least probable supposition, the vapour arising from the water may not be capable of being totally condensed.

The phenomenon of the boiling of fluids, is not very fatisfactorily explained; it is clear, I think, from the experiment of which I have given an account, that it cannot be attributed, in all cases, either to the escape of air from the interstices of water, or to the matter of fire, as it

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is called, pervading the water; for the water continued boiling for two hours after it was removed far from the fire; and the air, if it contained any, was utterly inadequate to the formation of the numerous bubbles. Boerhaave has remarked, that bubbles of the kind here spoken of contain no air, but he has not affigned the cause of their origin; Dr. Hooke ascribes them to the subtle parts of the water, which, when the pressure of the air is removed, (probably by means of an air pump) are able to acquire the form of vapours, by that fmall degree of heat which is left in the ambient air: \* and other philofophers + have adopted this idea, without hinting, at what Hooke supposed,

<sup>\*</sup> See Birch's Hist. of the Royal Society.

<sup>4</sup> The Abbè Nollet and Dr. Hamilton.

posed, a different degree of volatility in the parts of water.

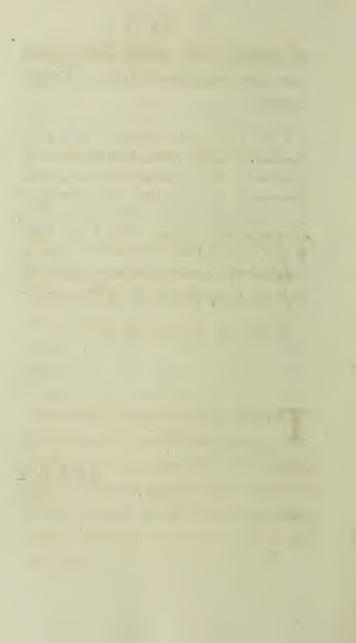
From what has been advanced we may conclude, that the Almighty, when he separated the chaotic mass into air and water, did not render these two oceans of matter, so wholly heterogeneous from each other, as that they should be incapable of contracting any union together; they have on the contrary, fuch a dispofition to unite, as feems to indicate their having had a common origin; and were it not for the intervention of heat, they would, probably, unite and again compose a common mass. The water on the furface of the earth is constantly replete with air, and the atmosphere is replete with water. The numerous tribes of aquatic animals, which

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which inhabit the ocean of water, would perish if it contained no air; and it is not an improbable conjecture, that the animals which exist in this ocean of air, would perish if it contained no water. The air, moreover, by being absorbed into the water, and afterwards separated from it by the action of the fun, to which it is daily exposed, is rendered abundantly more fit for animal respiration, than common air; and this purified air (the quantity of which, considering the great extent of the furface of the earth which is covered with water, must be very considerable) cannot but be one great mean of restoring to the whole mass of air, those falubrous qualities of which it is daily deprived, by the respiration of of animals, the putrefaction of bodies, the combustion of fuel, and other causes.\*\*

\* Dr. Priestley has observed, "that the same water, which, if examined immediately, gives only a small quantity of bad air, yields spontaneously about ten times the quantity of pure dephlogisticated air, after standing some time exposed to the sun." Phil. Trans. 1779, p. 377. An animal will live five times as long in what is called here dephlogisticated, as it will in common air of the best quality.

ESSAY





## E S S A Y VI.

Of Water in a solid State: of the Heat of Spring Water; and of a probable Cause of the Impregnation of sulphureous Waters.

THE mind of man admits with great reluctance, the truth of every testimony concerning matters of fact, which happen to be repugnant to the uniform experience of his senses: hence the general backwardness

wardness to believe the miracles recorded in the bible; and hence the Dutchman who informed the king of Siam, that water in his country, would fometimes, in cold weather, be fo hard that men walked upon it, and that it would bear an elephant if he were there, was esteemed a perfon unworthy of credit, the king, as Mr. Locke relates the story, faying to him, "Hitherto I have believed the strange things you have told me, because I look upon you as a sober man, but now I am fure you lie."\*

Mahine, the native of Borabora, could scarcely be persuaded, even by the information of his senses, of the reality of the same effect. The appearance of "white stones," as he called

<sup>\*</sup> Locke's Essay on the Hum. Und. B. IV. C. XV.

ealled hail, which melted in his hand was altogether miraculous to him; and when he had been with difficulty convinced that an extensive field of ice was not common land, he was determined at all events to call it "white land," by way of diffinguishing it from all the reft.\*

This determination of the savage was made in the true spirit of philosophy, for ice in small particles, is a species of earth, and in solid masses it may be considered as a kind of transparent stone. The waters, says Job, + speaking of the effect of frost, are hid as with a stone; that is, water conceals its nature, by assuming a stone-like hardness and consistence when it becomes ice. The Russians applied

<sup>\*</sup> Forster's Voy. Vol. I. p. 530.

<sup>†</sup> Chap. xxxviii. 30.

applied ice to the same purposes with stone, at the whimsical marriage of *Prince Gallitzen* in 1739; an house, consisting of two apartments, was built with large blocks of ice, the furniture of the apartments, even to the nuptial bed, was made of ice; and the icy cannon and mortars which were fired in honour of the day, performed their office more than once without bursting.\*

Ice, however, differs from all other earths and stones, not only in its melting in a much less degree of heat than any of them, but in its being subject to a constant diminution of its weight, when exposed to the open air, in the greatest degree of cold. It generally becomes shuid in the 33d degree of heat, as indi-

cated

<sup>\*</sup> Manstein's Mem. of Russia.

cated by Fahrenheit's thermometer; and Mr. Boyle by exposing in a good balance somewhat less than two ounces of ice to a sharply freezing air, a little before midnight, found it in the morning diminished in weight ten grains.\* It is probable, that this diminution of the weight of ice, is owing to the abrasion of its parts by the action of the air. The particles of air are thought to be larger than the particles of water, and may by their motion acquire force enough to separate the particles of ice; or if this should not be admitted, it must be remembered, that the air always contains a great quantity of water, the particles of which when converted into particles of ice, though in this country they are feldom

<sup>\*</sup> Boyle's Works, Fol. Vol. III. p. 66.

dom large enough to be feen, always make themselves felt by impinging upon our skin: these icy particles when put in motion may abrade the the furface of a mass of ice, and cause thereby a constant diminution of its weight. In confirmation of this explanation it may be observed, that ice fuffers no loss of its weight in a vessel devoid of air, nor in a close vessel full of air. \* That the icy particles, contained in a freezing atmosphere, should be able to act upon ice, cannot be a matter of difficult conception to those who recollect, that the hardest bodies in nature suffer a diminution of their weight, by the friction of the minute parts of the same kind of bodies; dia-

\* Hamilton on the Ascent of Vapours, p.

diamond dust being essentially necessary for the cutting or polishing of diamonds.

That water was diminished in quantity by being frozen was known. to Hippocrates; for he expressly says, that if a given quantity of water be frozen, and afterwards thawed, it will not fill the same vessel it would have done before it was frozen.\* Pliny was of the fame opinion with Hippocrates, and they both of them attribute this diminution of weight to the separation of the more subtile parts of the water during congelation. + The principal cause of the loss of weight, fustained by water when changed into ice, feems to be the incessant action

<sup>\*</sup> Hippoc. de Aqua.

<sup>†</sup> Plin. Hist. Nat. Lib. II. S. 61. & Lib. XXXI. S. 3.

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action of air upon its furface; it is true, however, that water is, by freezing, deprived of the greatest part of the air with which, in its sluid state, it is ordinarily saturated; and this separation of its air may contribute something towards the diminution of the water's bulk; since water when saturated with air, is somewhat greater in bulk than when deprived of it.

It is easy to apprehend, that the loss of weight which any given quantity, suppose a cubic foot, of ice will suffer by exposure to the air in a given time, will depend, partly upon the hardness or softness of the ice, partly upon the temperature of the atmosphere, with respect to the degrees of cold and humidity, partly upon the velocity of the wind which brushes

brushes its surface, and probably enough upon the agency of other causes with which we are less acquainted. Some philosophers have estimated in general terms, the loss of weight sustained by a certain weight of ice, without specifying the magnitude of the ice's furface; others, with more accuracy, have mentioned both the weight and furface of the ice exposed to the air, but then they have either omitted to speak of the ice's confistency; the temperature of the atmosphere; the force and direction of the wind; or they have expressed themselves in very indefinite terms concerning these points, so that we cannot be faid to have hitherto gained, from their experiments, any precise information upon the subject. As to the fact itself, the most com-

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mon observation is sufficient to ascertain us of its truth. In long continued frosts, the ice formed in ponds and other small collections of water, is sensibly diminished every day, and often wholly evaporated; and a fall of snow may be seen considerably wasted in a few days, in the severest season.

Notwithstanding this diminution of weight, to which both ice and snow are subject in the coldest weather, and the thaw which they experience in the hottest, yet some have doubted whether the quantity of congealed water, be not an increasing quantity upon the surface of the earth; and have even thought, that the globe of the earth must in process of time resemble an egg, having its diameter from pole to pole, longer than the

equatorial diameter, on account of the constant accumulation of frozen water at the two poles. — "After so many years lapse it cannot be, I think, but that the diameter of the earth from pole to pole, from the top of the snow at one end of the earth, to the top of it at the other end, is much longer, than in any part under the equator, though at the creation it were (as I believe) made spherical." \*

In some mountainous countries, the proportion between the snow which falls at one season of the year, and that which is dissolved in another, approaches so near to an equality, that upon the same spot, the snow may in one year be seen quite through the year, in another, the

<sup>\*</sup> Childrey's Brit. Bacon. p. 148.

the last speck of it will vanish in a few weeks or days, before a new fupply is brought by the approach of winter. In colder climates, the utmost power of the summer sun is not able to melt all the fnow which falls in the winter. In afcending mount Etna, the Alps, or the Andes, though the lower parts are found to be rich in vegetation, yet you foon come to a region covered, as it should feem, with everlasting snow; the height at which this region commences, does not admit much variation in the same latitude, but is very different in different latitudes. It begins at the distance of near three miles above the level of the fea under the equinoctial line; and at each pole, probably, it is not removed from that level so many hundred feet

feet; it is found to be 600 yards nearer to the level of the fea at Teneriffe than under the equator; and above 1200 yards nearer in Switzer-land than at Teneriffe\*.

Not only the tops of high mountains in every quarter of the globe are covered at all seasons of the year with snow, but the ocean both in the northern and southern hemisphere is, in high latitudes, replete with immensemountains, and extensive plains

of

\* Histo. Nat. des Glaciers Suisse — the author says, ensin la plupart des Montagnes voisines des poles sont convertes jusqu'à leur pied de neiges perpetuelles. This observation must not be admitted without restriction if it be at all true, since in Greenland, and in the latitude 79 degrees, 44 minutes north, the seet of the mountains are in certain seasons freed from snow. See Crantz Hist. of Greenland, Vol. I. p. 30: and Phipps Voy. p. 52 and 70.

of ice, in the greatest heats of summer; and hence it has appeared probable to many, that both the snow upon the land, and the ice upon the sea, receive an augmentation every year, from the continued agency of the same cause which first produced them.

A philosopher, well acquainted with the nature of the Alps, expresses himself upon this subject in the following manner, "one cannot doubt concerning the increase of all the Glaciers of the Alps: for their very existence is a proof, that in preceding ages the quantity of snow which has fallen during the winter, has exceeded the quantity melted during the fummer. Now not only the fame cause still subsists but the cold, occasioned by the mass of ice already formed,

formed, ought to augment it still farther, and thence both more snow ought to fall, and a less quantity of it be melted."\* If this be admitted, the time will undoubtedly come when the fea will be diminished in depth, if not dried up by the conversion of the water, which is daily raised from it, into snow or ice; and had the world been as old, as some are fond of supposing it to be, we fhould, probably, have had no water upon its furface at the present day. However it must be owned, that no argument can be drawn against the antiquity of the world, from this consideration, because there is reason to believe that the ice and fnow upon the furface of the earth, are not annually increasing in quantity.

De Luc de l'Atmosphere. Vol. II. p. 328.

tity. For besides the heat of the air in fummer, there is another cause which tends to prevent an indefinite augmentation of congealed water the internal heat of the earth. The general heat of the springs of water, situated deep in the bowels of the earth, is 48 degrees; in mountainous countries, I suspect it to be somewhat less, but sufficient, notwithstanding, for the purpose here mentioned. When the snow, incumbent on any spot of ground, is but thin, it may so far cool the earth, that its internal heat may not be able to dissolve it; but when the bed is thick enough to protect the earth from the influence of the atmofpherical cold, that furface of the fnow which is contiguous to the furface of the earth, may, even in the

coldest winters, receive more heat from the earth than it does cold from the atmosphere, and, on that supposition, I see no absurdity in admitting, that it may be dissolved at all seasons of the year.

The fact I believe is certain, that streams of water iffue from the bottom of the Glaciers in the Alps, in the greatest severity of winter; so that whether the internal heat of the earth be admitted or not, as a cause fufficient to explain the phenomenon, a constant thaw of the ice or snow, which is contiguous to the furface of the earth in the Alps, cannot be denied; and this, added to other causes, may render it probable, that the quantity of congealed water has its limit even, in the coldest climates.

The ordinary hear of spring water, which does not feel the vicissitudes of the temperature of the atmosphere, is here said to be 48 degrees of Fahrenheit's thermometer; it may be worth while to add a few remarks on this subject.

In August 1778, when the heat of the air was 72 degrees, I tried on the same day, the temperature of several fprings, reputed cold, in the neighbourhood of Matlock; and I found them varying in heat from 50 to 54 degrees. This variation, probably, proceeds from their fubterraneous passages being situated at different distances from the surface of the earth, which was then much warmed by the heat of the fummer. Or it may proceed from the springs being more or less mixed with the

water

water which supplies the warm baths, the heat of that water being 68 degrees. There is a subterraneous passage upon the side of the hill near the new bath at Matlock, which terminates in a large cavern, fituated under one of the fields in the midway between the new and the old bath; and from this cavern, which is always full, issues the warm water which fupplies both the baths, and it may probably ooze out in different directions, and in different quantities, fo as to make the neighbouring springs participate more or less of its warmth.

At Lord Godolphin's house on Gogmagog hills, near Cambridge, there is a well, above 230 feet in depth, which is dug through a stratum of chalk; I have frequently examined the heat of the water of this well,

and

and constantly found it to be 50 degrees. At Cherry-Hinton, a village situated at the bottom of these hills, there issues from the chalk a very copious spring, the heat of this water as it bubbles out of the earth, is, at all feasons of the year, 50 degrees. I have tried the heat of some deep wells dug in chalk at Bury St. Edmund, and found it variable from 50 to 52 degrees. — "It has been long and generally observed, that as far as the limestone extends, that tract of ground makes the snow that falls on it, thaw or melt fooner than it does on the neighbouring lands."\* This is Mr. Boyle's obfervation concerning some limestone land in Ireland, and he fays its truth was confirmed to him by a Derbyshire

<sup>\*</sup> Boyle's Works, Vol. IV. p. 278.

shire miner, who affured him, that on contiguous districts of land, snow was observed to dissolve much sooner on the foil which covered limestone, than on that which covered freestone. If these observations may be depended on, we may, perhaps, in general infer, that the heat of calcareous strata is greater than that of other kinds of strata; and this would furnish a reason for the springs in chalk countries being of the warmth of 50, though the ordinary heat of springs be not above 48 degrees.

In the middle of summer, when the air was 72 degrees hot, I tried the heat of some springs at Harrowgate in Yorkshire. Pump water at the Granby Inn 48 degrees. — Old Spaw 48 degrees. — Pewit or Tewit well

48 degrees. - Sulphur well 50 degrees. The cold well at Buxton, examined at the same time of the year, was 48 degrees, and the famous Spaw at Llanrhaid'r in Denbighshire was also 48 degrees; St. Winifred's well at Holywell in Flintshire, was confiderably warmer, the thermometer when held in the spring as it rose out of the earth, standing at 54 degrees. I have tried a great many other springs in different parts of Great Britain, and found the heat of most of them to be included between the limits of 48 and 54 degrees, the mean of which is 51. Springs on the fides of high mountains, may, probably, participate of the cold which is found to be greater in elevated than in low fituations. There is a spring by the side of the turnturnpike road leading over the high ground called Otley Shevin in Yorkshire; I observed the heat of this spring in September, when the air was warmed to 62 degrees, to be not 48, but only 45 degrees. The mean heat of springs near Edinburgh is said to be 47, and at London 51 degrees: † this diversity depends, probably, on the different elevations of London and Edinburgh above the level of the sea.

I have mentioned the Sulphur well at Harrowgate, according to its usual appellation at that place, without taking upon me to decide the long controverted question, concerning the existence of sulphur in that and other waters of the same kind. "Sulphur has been long esteemed a mineral

† Philof. Trans. 1775, p. 460. VOL. III. N

mineral body very common to be met with in waters; and all those waters which have a strong fetid fmell, refembling that of a foul gun, have been esteemed to be more or less impregnated with fulphur. However, Dr. Hoffman feems to doubt much of its existence in the greater number of such waters; and Dr. Lucas has affirmed, that it is not to be found in the form of fulphur in any water whatever; not even in that of Aix la Chapelle, where a true and perfect sulphur is found on the upper parts of the conduits through which the water passes; for he says, that, strictly speaking, these waters do not contain fulphur fubstantially dissolved in them, but are impregnated with a phlogiston and an acid, the principles of fulphur; which being-

ing in a volatile state are sublimed, meet on the furface of the conduits, and there unite into a true and perfect fulphur, which did not naturally exist in the water."+ The author, from whom I have made this extract, informs us, that Dr. Rutty maintains the existence of sulphur in mineral waters; and that both Dr. Shaw and Dr. Short found fulphur in Harrowgate water. Notwithstanding the testimony of such eminent physicians, the more recent opinion of a physician, whom Dr. Monro confulted on the subject in 1768, is against the existence of sulphur in fuch waters. "I have taken particular notice of every appearance of the Harrowgate waters, and must own

<sup>†</sup> Monro on Mineral Waters, Vol. I. p. 30. & 196.

own I never observed any appearance of fulphur floating in them, nor any fcum at the top of the well; neither could I meet with any person in that quarter, who remembered the appearance of real fulphur fublimed, upon taking up the slones at the bottom of the well, as mentioned by Dr. Neale." † - I beg leave to add my own observation on the subject, which I made in 1780. The water in the well rifes into a circular stone bason; a whitish crust adheres to the stone, where it is contiguous to the furface of the water; I scraped off a portion of this crust, and putting it on a hot iron, I found that it burned with the flame and smell of fulphur. I do not think that this experiment absolutely warrants us to

conclude, that actual fulphur is contained in this, and other waters generally denominated fulphureous; we justly infer from it, that something is sublimed from the water, which either of itself is sulphur, or which in conjunction with the air, or some other principle, constitutes sulphur.

The profecution of this subject would lead to speculations too abstructe for my design; the following experiment, however, which I have frequently made, will, I hope, throw no inconsiderable light on the cause of the impregnation of sulphureous waters in general.

The acid of vitriol does not act upon the common Derbyshire lead ore, except when it is affished by heat, it then dissolves it, and a great

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escape of air is observed; I made this air, as it was discharged from the ore, pass through a high bended tube into a bottle full of pump water: the water, in a very little time, acquired the fetid smell of Harrowgate water, - its tafte was the same as that of fuch fulphureous waters as contain no falt, - it was perfectly iransparent, but in the course of 24 hours it became cloudy and lost most of its smell, - it did not suffer any precipitation by the addition of the acid of vitriol, - filver was blackened, both by being put into this water, and by being exposed to the vapour which arose from it; from all these circumstances, it may properly enough, I think, be called an artificial sulphureous water.

I have observed the same pheno-

mena when, instead of lead ore, I used black jack: and I remember that once having placed a bottle, containing black jack and acid of vitriol, so that its neck leaned against a plaistered wall, I observed, some days afterwards, that the wall was stained, to the distance of above a foot from the mouth of the bottle, of a purple colour, resembling the purple sediment often found in sulphureous wells.

Air of the kind here spoken of may be separated from other substances, as well as from lead ore and black jack, and by other means, as well as by the acid of vitriol; and it seems very probable, that the waters usually called sulphureous, are impregnated with this kind of air, which has been separated, in the bowels

bowels of the earth, from particular minerals, especially sulphureous ones: it has been remarked of Harrowgate water, that as it springs up it is clear and sparkling, and throws up a quantity of air bubbles.

During the process of impregnating water with air, by diffolving lead ore in the acid of vitriol, a part of the glass tube was coated with a thin pellicle of fulphur, which had accompanied the air in its ascent; May not the fulphur fublimed from Harrowgate water, have accompanied the air which gives it its smell? Is it certain that this kind of air does not confift of attenuated parts of fulphur, which have acquired an elastic force, and which cannot be condensed in water? Or, is it not more probable, that this kind of air is one of the constituent parts of sulphur than sulphur itself? Does this air, and the inflammable air, separable from some metallic substances, by solution in acids, consist of oleaginous particles in an elastic state?

If the reader wishes to impregnate common water with the fulphureous properties of Harrowgate water, he may do it in the following fimple manner. - Into an apothecary's vial, holding four or five ounces, put fome pounded lead ore, and pour upon it some acid of vitriol; (there is no occasion to be solicitous about the proportions of the lead ore and acid, for if there be more or less ore than the acid can dissolve, still air enough for the purpose will be discharged;) wrap a few folds of wet linen round one end of a bended tube,

tube, infert this end into the neck of the vial so closely, that no air may pass out of the vial except through the tube; the end of the tube should be at some distance from the surface of the acid. Put the other end of the tube into a bottle full of water; then, by fetting the vial on the hot bar of a grate, or by some other means, heat the acid, and as foon as it is heated, it will begin to act on the lead ore, and a great quantity of air will be discharged, which will pass through the tube into the water in the bottle, and in a few minutes the water will be strongly impregnated with the fulphureous properties of Harrowgate water. Befides its fulphureous impregnation, Harrowgate water contains sea falt, and most other fulphureous waters contain

contain some falt or other, so that, to make a complete imitation of them, the salts which they severally hold should be added in due proportion, to the water impregnated with the air here spoken of.

Though I am greatly disposed to believe, that sulphureous waters are impregnated with their peculiar smell and taste, after the manner I have described; yet to assist the reader's conjectures concerning the origin of this impregnation, I will mention another way in which it may be supposed to arise, and which will account for the saline taste, as well as the smell of the water.

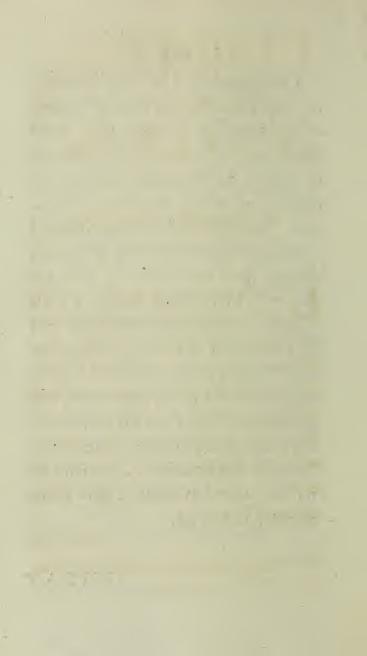
I know not whether any species of maritime plants, containing sea salt, will impregnate water with a sulphureous smell by means of putre-faction;

faction; nor whether all of them will do it by means of combustion, but that one of them will do it I can have no doubt: I allude to the bladder fucus or sea wrack, which is burned on our coasts for the making of Kelp. It has been mentioned before, \* that fea wrack when burned to a black coal, will yield, by being boiled in water, a great quantity of common falt; and I would now remark, that the water extracts from the black ashes, not only a great quantity of common falt, but something else also, by which, without losing its transparency, it acquires both the smell and sulphureous taste of Harrowgate water, and by which it is enabled, like that water, to blacken filver and white paint.

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<sup>\*</sup> Vol. I. p. 137.

This fomething I am sensible may be what chemists call liver of sulphur, or an union of fulphur with fixed alkali, and it would not be difficult to explain its formation during the combustion of the sea wrack; no sulphur however can be precipitated from the water by the acid of vitriol, though that acid turns it, as is the case with Harrowgate water, a little cloudy. The air extracted from iron by the acid of fea falt, impregnates water with a smell somewhat resembling that of Harrowgate water, but its difference both from the natural and the artificial fulphureous waters, may be eafily diffinguished, especially after the water has flood a few hours exposed to the air.





## E S S A Y VII.\*

## Of Derbyshire Lead Ore.

EAD ore, as dug out of the mine, is generally much mixed with spar, limestone, and other substances, bulk for bulk, lighter than the ore itself. It undergoes various dressings before it becomes a merchantable commodity, the general tendency of which is to free it, as much as possible, from every heterogeneous impurity.

Suppose

The substance of this Essay was printed in the Philos. Trans. 1768.

Suppose that a cubic foot of lead ore, which contained no spar or other extraneous matter, would weigh 7800 ounces, and that a cubic foot of spar, which contained no lead ore or other foreign substance, would weigh 2700 ounces, then would a mixture, confifting of a cubic foot of pure lead ore and a cubic foot of pure spar, weigh 10500 ounces, and one cubic foot of fuch a mixture would weigh 5250 ounces. It is obvious that, according to the different proportions in which the particular kinds of spar and lead ore here assumed are supposed to be mixed together, a cubic foot of the mixture will have different weights, the limits of which are on the one hand 7800, and on the other 2700 ounces; it never can weigh so little as 2700 ounces, for then

then it would confist intirely of spar without any lead ore; nor can it ever weigh so much as 7800 ounces, for then it would confist intirely of lead ore without any spar.

From this view of the matter it is evident, that the purchasing of lead ore by the measure, which is the general, though not the universal custom in Derbyshire, is a mode liable to some exception; since a dish, containing any definite measure, must have different weights, according as the ore with which it is filled is more or less free from spar. And it is scarce possible, by repeated dressings, to separate all the spar from an ore, or equal portions of it from equal portions of ore.

There is a diversity, however, in the weights of equal measures of lead VOL. 111. O ore

ore, which, probably, does not arise from sparry or other heterogeneous accretions, but from the nature of the ore itself. I have carefully calculated the weight of a cubic foot of many of the Derbyshire lead ores; the weight of a cubic foot of the lightest which I met with was 7051 ounces, and the weight of a cubic foot of the heaviest was 7786 ounces; the difference amounting to between a ninth and a tenth part of the weight of the lightest. There are, probably, other ores of lead, the weights of equal bulks of which differ more than these here mentioned; but the difference between these is sufficient to shew the great uncertainty of purchasing lead ore by the measure, fince ten dishes of one fort of ore may not weigh more than nine dishes

of another fort, though both the forts be equally well dreffed.

Lead ore is not always of the same goodness in the same mine, nor even in the same part of the same mine; and, what is more remarkable, the different parts of the same lump of ore have in equal bulks different weights. I could not easily have believed this, unless a variety of experiments had convinced me of the sact.

They were employed lately at Holy-well in smelting a lead ore from the Isle of Man; the ore was rich in silver. A lump of this ore, weighing about ten ounces, was broken into several pieces, and such of the pieces were selected as appeared to the eye to be wholly pure. I estimated the weight of a cubic foot of six of these pieces,

and

and found that a cubic foot of the lightest kind would have weighed 6565 ounces, and a cubic foot of the heaviest kind would have weighed 7636 ounces. Supposing the weight of a cubic foot of water to be denoted by 1000, the mean weight of a cubic foot of the six different pieces of this ore, may be expressed by 7115 avoirdupoise ounces.

A very pure specimen of tessellated lead ore, from a mine near Ashover in Derbyshire, was broken into six pieces, weighing near one ounce each. A cubic foot of the lightest of these pieces would have weighed 7326 ounces, and a cubic foot of the heaviest would have weighed 7786 ounces. The mean weight of a cubic foot of the six pieces was 7566.

At the same mine they frequently meet with small quantities of steelgrained lead ore. Six different pieces of the same lump of this kind of ore were chosen, each of which appeared quite free from spar and every other impurity. A cubic foot of the lightest of these pieces would have weighed 7188 ounces, and a cubic foot of the heaviest would have weighed 7442 ounces. The mean weight of a cubic foot of the six pieces was 7342.

Other lumps of ore, from different mines, were respectively broken into different pieces, and scarcely any two equal pieces of the same lump were observed to agree in weight. This diversity in the weights of equal bulks of the several pieces of the same lump of ore may be owing, either-

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which the constituent parts of the ore are combined in the several pieces; or to the different quantities of extraneous substances imperceptibly mixed with them, or, which seems most probable, to a diversity in the size or configuration of their pores.

But be the cause of this diversity what it may, the fact, I believe, is certain, and by no means singular; for not to mention the varieties observable in the weights of equal bulks of different pieces of roll brimstone, of corrosive sublimate, of cast steel, and other factitious substances, the natural spars generally found along with lead ore are subject to a similar diversity, though not, perhaps, in an equal degree.

A piece of rhomboidal, otherways called

broken into four smaller pieces, the weights of a cubic foot of each of which were 2675, 2687, 2715, 2723; the medium of the four is 2700 ounces. Mr. Cotes fixes the weight of a cubic foot of Iceland crystal at 2720, and Wallerius fixes it at 2700 ounces.

The weights of a cubic foot of four pieces of the same lump of cubical spar were 3204, 3218, 3222, 3231; the medium of the four is 3219 ounces. — Most of the spars met with in Derbyshire are either rhomboidal or cubical; they are easily distinguished from each other by a view of their shape, when their angles can be discerned; and when the shape cannot be easily seen, the nature of the spar may be ascertained.

by touching it with an acid; the rhomboidal spar always effervescing with an acid, and the cubical refifting its action. The lead smelters. make great use of the cubical spar as a flux for fuch lead ores as do not readily melt: it is curious to fee its effect; a few shovels full of it, thrown. upon a heap of red hot ore, immediately melting down the ore into a liquid, though the longest continuation of the fame degree of heat, without the addition of the spar, would not have been sufficient for the purpose.

Six ounces of fine tessellated lead ore were put into a crucible and exposed, at first, to a gentle, and afterwards to a strong fire: the ore grew red, and emitted fumes which smelled of sulphur; at length it melted, and

and the fumes became very copious; they were accompanied with a yellowish flame upon the surface of the melted ore, and when collected had a whitish appearance. The crucible after the ore had continued a full: hour in perfect fusion was taken from the fire, and when it was, cold it was broken. The mass which it contained weighed five ounces and. an half; there was no scoria observable on its furface, nor were any particles of metal formed, it was still an ore of lead.

The mass remaining from the last experiment was put into a fresh crucible, and exposed to a strong melting heat; the sumes which arose from it seemed to be heavy; they brooded over the surface of the melted mass in undulating stames, which

which now and then appeared like burning zinc.\* The lead was now formed, and many particles of it were fublimed to at least fix inches above the surface of the liquid in the crucible. After letting the crucible continue two hours in this state, I poured out its contents, and found them consisting partly of lead, partly of lead ore, and partly of a very minute portion of brownish scoria. I repeated this experiment with the same success.

These experiments prove, that some substance or other is contained in lead ore, which must be dispersed before the ore can be formed into lead; and they shew too, that it requires

<sup>\*</sup> It may deserve to be inquired whether zinc may not be contained in lead, iron and other ores, more frequently than is supposed.

quires a considerable time to effect the dispersion of this substance, since fix ounces of ore, though kept three hours or more in complete fusion, were not wholly brought into the form of lead; they instruct us also to believe that the lead in this kind of ore is in its metallic state, as the ore was changed into lead without the addition of any fubstance containing the inflammable principle; and, lastly, they render it probable, that the fumes, arifing from melted ore, carry off with them no inconsiderable portion of the lead itself. At the great fmelting houses in Derbyshire, they put a ton of, ore at a time into the furnace, and work it off in eight hours; the ore, might be wholly melted in one hour, but the lead, perhaps, is not formed in the greateft

est possible quantity in eight hours.

Some fine tessellated lead ore from Derbyshire was pounded into small lumps, each about the fize of a pea, and carefully picked from spar and other impurities. Sixteen ounces of this ore, thus previously cleansed, were distilled in an earthen retort; as foon as the ore felt the fire, the stopple of the quilled receiver had as strong smell, resembling that of the inflammable air, separable from some metals by folution in acids; foon after a small portion of a liquid came over into the receiver; the fire wasthen raised till the retort was of a white heat, when a black matter began to be sublimed into the neck of the retort; the operation was then discontinued. This experiment was undertaken with a view of seeing whewhether fulphur could be separated from lead ore, as it may be from fome species of the pyrites, by distillation, and it appears from the issue of the experiment that it cannot, at least in the degree of heat which is requisite for subliming the ore. Upon breaking the retort I found, that the ore had been melted during the operation, for there was a confiftent cake of ore of the figure of the bottom of the retort; the weight of this cake was fifteen ounces' and an half, the weight of the liquid in the receiver, and of the black matter which had been fublimed, did not together amount to one quarter of an ounce, so that a quarter of an ounce or more had been dispersed, probably, in the form of air, or some elastic sluid. The ore by this pro-

cess had lost one thirty-second part of its weight. The liquid did not effervesce with either acids or alkalies; nor did it produce any change in the colour of blue paper, yet I am certain, from experiment, that one drop of oil of vitriol, though diluted with two ounces of water, would have produced a sensible redness on the blue paper which I used. The liquid, notwithstanding, had an acid taste, and a pungent smell, refembling that of the volatile vitriolic acid. The black matter which had been fublimed into the neck of the retort, was examined with a microfcope, and it appeared to be pure dead ore. The melted ore which was found at the bottom of the retort, had not any appearance of scoria, or of lead, upon its surface.

Some

Some phenomena attending this experiment deserved, I thought, a further investigation. I therefore distilled another 16 ounces of ore, but with a fire stronger and continued for a longer time, than in the preceding experiment: the quantity of liquid was much the fame, there was a fmell of fulphur, and, perhaps, to the amount of half a grain of fulphur was found in the receiver; the ore was in this experiment fublimed into the neck of the retort, to the thickness of one fourth of an inch. There was found, as before, a cake of melted ore at the bottom of the retort, but no sensible portion of either lead or scoria; \* so that we may safely

con-

I have faid no fensible portion; there was, however, an appearance of *scoria* adhering to the side, and an appearance of *lead* adhering

conclude, that lead ore cannot be decomposed by the strongest fires in close vessels, but that it may be sublimed in them. The ore had lost near an ounce of its weight.

Though the experiment is sufficiently troublesome, I was not deterred from making it once more; for I wanted to see whether lead ore could be wholly sublimed; as I thought that philosophers might thereby form some conjectures, of the efficacy of subterraneous fires in sublim-

ing

adhering to the bottom of the retort; but the quantity of each was exceedingly small, and they were both, probably, produced from that minute decomposition of the ore which produced the sulphur, and which would not, I think, have taken place in any degree, had there been no communication with the external air; but the orifice of the quilled receiver was not always closely stopped during the distillation. ing lead ores, and, perhaps, ores of other metallic substances. The event of this third experiment was perfectly correspondent to that of the two former, with respect to the production of liquid, and the separation of air, which was caught in a bladder, but was not found to be inflammable: the lead ore too was so plentifully sublimed into the neck of the retort, that it quite plugged it up for above three inches in length. Upon discontinuing the fire, which had been raised to a degree of heat exceedingly great, I found the retort was cracked, and that the cake at its bottom was very different from what was found at the bottom of the other retorts, which had stood the fire without cracking, for this cake was covered with a black glaffy fco-VOL. III.

ria tof an inch in thickness, and the ore which laid under it, was in part changed into lead, and the whole of the ore did not weigh quite ten ounces, fo that above 6 ounces had been loft by escaping through the crack. By a communication with the air through the crack, the ore was decomposed, and thus both lead and scoria were formed, which in the other experiments, for want of fuch a decomposition, could not be formed. There was a thin coat of fulphur also which lined the inside of the receiver, and this fulphur, probably, arose from the decomposition of the ore, fince none, or next to none, was observed in the other di-Billations of the ore. I found that the weight of a cubic foot of the ore, which had been sublimed into the the neck of the retort, was 7500 ounces; which sufficiently agrees with the weight I had before ascertained of this kind of ore. A cubic foot of the black glassy scoria weighed 3333 ounces; and the metallic cake which laid under it, and which consisted partly of lead, and principally of ore not quite changed into lead, gave 8738 ounces to the cubic foot.

Finding that fulphur could not be feparated from lead ore by distilling it in close vessels without addition, and yet being much disposed to think, that it contained a considerable portion of sulphur, I first thought of distilling it with charcoal dust, iron silings, sand, and other additions; but recollecting that sulphur might be separated from antimony

by

by folution in acids, I thought it not improbable, that it might be feparated from lead ore by the same means, and the success of the following experiment abundantly justified the conjecture.

Upon ten ounces of lead ore, cleansed as in the preceding experiments, I poured five ounces of the strongest fuming spirit of nitre; this strong acid not feeming to act upon the ore, I diluted it with five ounces of water; a violent ebullition, accompanied with red fumes, immediately took place; the folution of the ore in this menstruum became manifest, and when it was finished, there remained floating upon the furface of the menstruum a cake of fine yellow fulphur, perfectly refembling common fulphur.

I repeated this experiment a great many times, in order to afcertain the quantity of fulphur contained in lead ore, and separable therefrom by folution in acid of nitre. The refults of different experiments were feldom the same: the matter separable from the ore by folution, after being repeatedly washed in large quantities of hot water, in order to free it from every faline admixture, fometimes amounted to more, fometimes to less than one-third of the weight of theore. This matter may, for the fake of distinction, be called crude sulphur. Its apparent purity might induce as belief that it contained no heterogeneous mixture, yet the following experiments shew how much we should be deceived in forming fuch a con-

P. 3. jecture,

jecture, and how rightly it is denominated crude fulphur.

From one hundred and twenty parts, by weight, of lead ore, I obtained, by folution in acid of nitre, subsequent washing in hot water, and drying by a gentle fire, forty parts of a substance which looked like sulphur: these forty parts were put on a red-hot iron, the fulphur was made manifest by a blue flame and pungent smell. When the flame went out, there remained upon the iron unconfumed twenty-fix parts of a greyish calx; the weight of the sulphur which was confumed must therefore have amounted to fourteen parts, or between one eighth and one ninth part of the weight of the ore. It has been observed, that the weight of the matter, separable from lead ore by

by folution in acid of nitre, fometimes exceeded, and fometimes fell short of, one third part of the weight of the ore; this variety, as far as I have been able to observe, does not extend to the quantity of fulphur contained in a given quantity of ore, it depends upon the quantity of calx remaining after the burning of the fulphur. Different lead ores will, doubtless, contain different quantities. of fulphur; but that the fulphur contained in the lead ore which I examined, constitutes between one. eighth and one ninth part of the weight of the ore, is a conclusion. upon which, from a variety of experiments, I am disposed to rely.

There are said to be annually smelted. in Derbyshire about ten thousand tons.

of lead ore; \* now if means could be invented (which I think very poffible) of faving the fulphur contained in ten thousand tons of ore, supposing that the ore should only yield one tenth of its weight of fulphur, though it unquestionably contains more, Derbyshire alone would furnish annually one thousand tons of fulphur, the value of which would annually be about fifteen thousand pounds. I mention this circumstance thus publicly, in hopes that the lead fmelters may be induced to profecute the subject. If the sulphur contained in lead ore could be collected," it would not only be a lucrative business to the smelters, but a great faving to the nation. We at present

<sup>\*</sup> This estimate is, I have reason to think, too high.

present import the sulphur we use, and the confumption of this commodity is exceeding great, in the making of gunpowder, in forming the mixture for covering the bottom and fides of ships, \* and in a great variety of arts. The fmelters need not be apprehensive lest the quality of the ore should be injured by extracting the fulphur. Eighteen hundred weight of ore, from which the fulphur has been extracted, will certainly yield as much lead as twenty hundred weight of ore, from which the fulphur has not been extracted, and it will, probably, yield more. Arfenic is extracted

\* This mixture is made of one part of tallow, of one part of brimstone, and of three parts nearly of rosin. The tallow and rosin are melted together, and the brimstone is stirred into them; 140 pounds of brimstone is enough for a vessel of 140 tons.

tracted from a particular ore in Saxony, by roasting the ore in a furnace, which has a long horizontal chimney; the chimney is large, has many windings and angles, that the arsenical vapour which arises from the ore may be the more eafily condensed: the arsenic attaches itself like foot to the chimney, and is from time to time fwept out. It is very probable, that by some such contrivance the fulphur contained in lead ore might be collected. The fmelters call every thing fulphur which is volatilized during the roafting or fluxing of an ore; but none of those with whom I have conversed, had any notion that common fulphur could be separated from lead ore.

The greyish calx which remained upon

upon the iron after the fulphur was confumed, was put upon a piece of lighted charcoal; the heat of the charcoal being quickened by blowing upon it, a great number of globules of lead were formed upon its furface. From hence it appears, that this calx is not an unmetallic earth contained in the ore, which the acid of nitre could not dissolve; but a calx of lead, probably produced by the violent action of the acid, and which, by the addition of phlogiston, may be exhibited in its metallic form. The quantity of this calx depends much upon the action of the acid upon the ore; if that action is violent, the calx is in greater abundance than if it be moderate; and I am not certain whether the experiment might not be fo managed,

managed, that there would be little or no calx remaining; that is, a given quantity of ore might be fo dissolved in the acid of nitre, that nothing would remain undiffolved except the fulphur. But I have not yet perfectly fatisfied myself as to the constituent parts of lead ore. I am certain that it contains lead, and fulphur, a liquid, and air: of the existence of the three first there can be no doubt, from what has been faid, and the air is rendered beautifully apparent by the following experiment.

Let some lead ore be reduced into a fine powder, put it into a narrowbottomed ale glass, fill the glass three parts with water, drop into the water a portion of the strong acid of nitre, you may judge of the requifite quantity by feeing the folution commence, and you will observe the ore univerfally covered with bubbles of air, these will buoy the ore up in large tufts to the furface, and the air will continue to be separated from the ore till the acid becomes faturated with the lead. The falt arising from the union of the nitrous acid to the lead often appears crystallized upon the furface of the menstruum in this experiment; and if, when the menstruum is in that state, a little fresh acid be added, the falt inftantly crystallizes and falls down to the bottom of the glass, the acid having absorbed the water which held it in folution. When lead is diffolved in the manner here mentioned, by a very diluted acid of nitre, there is no appearance of fulphur phur upon the surface of the menstruum, there is found at its bottom a black matter which is the sulphur.

But though lead, and fulphur, a liquid, and air, \* are unquestionably constituent parts of lead ore, I do not take upon me to fay, that they are the only constituent parts: it is well known, that, during the fmelting of lead ore, a third part or more of its weight is fomehow or other loft, fince from one and twenty hundred weight of ore, they feldom obtain above fourteen hundred weight of lead. What is lost partly consists of a scoria which floats upon the furface of the lead during the operation of smelting, and partly of what

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<sup>\*</sup> I have separated inflammable air from lead ore, by dissolving it in the acid of sea salt.

is sublimed up the chimney and dissipated in the air. The scoria, I apprehend, would be very little, even from a ton of ore, if the ore was quite free from spar: it is the spar which is mixed with the ore that constitutes the main portion of the scoria. \* I have in my possession a solid mass of scoria, which accidentally flowed out from a finelting furnace, and which in colour and confiftency perfectly refembles grey lime-stone; it receives a polish as fine as marble, and it might, perhaps, with advantage be cast into moulds for paving stones, chimney pieces, and other matters.

\* The spar without question augments the quantity of the scoria, yet the lead ore which appears to the eye to be quite free from spar, yields a considerable portion of a black glassy scoria, when urged with a sufficient fire.

matters. It arises from the spar mixed with the ore, and, by the addition of cubical spar to the ore during its fusion, its quantity might be increased at no great expence, in any proportion. That part of the ore which is fublimed and dispersed in the air, consists partly of the sulphur which is decomposed, and partly of lead; this sublimed lead attaches itself in part to the sides of the chimney of the fmelting furnace; the rest of it flies up into the air, from whence it falls upon the ground, poisoning the water and herbage upon which it settles. This sublimed lead might be collected either by making it meet with water, or with the vapour of water during its ascent, or by making it pass through an horizontal chimney of a sufficient length.

It is not easy to determine with precision the quantity of this sublimed lead; a general guess, however, may throw fome light upon the fubject. They usually at a smelting house work off three tons, or fixty hundred weight, of lead ore every twenty-four hours; the fulphur contained in fixty hundred weight of ore, we will suppose to be seven hundred weight, and the lead to be forty hundred weight; the air, liquid, scoria, and fublimed lead, must together, upon this supposition, amount to thirteen hundred weight; now, admitting three hundred weight of the thirteen to be fublimed lead, it is evident that, could it be collected, there would be an annual faving at each smelting house of above fifty tons, which, supposing it to be worth VOL. III.

worth four pounds per ton, would amount to above two hundred pounds a year. The price, if not the quantity of lead fublimate, here affumed is, probably, below the truth; but my end is answered in giving this hint to persons engaged in the smelting business.

The following experiments, though upon a different subject, may not be unacceptable to the lovers of chemistry, as I do not remember to have any where met with them.

It is commonly known, that the furface of melted lead becomes covered with a pellicle of various colours. I undertook fome experiments in the course of last winter, with a view to ascertain the order in which the colours succeeded each other. The lead which lines the

boxes in which tea is imported from China happening to be at hand, fome of it was melted in an iron ladle; but I was much furprized to find that its furface, though it was presently covered with a dusky pellicle, did not exhibit any colours. Imagining that the heat was not fufficiently strong to render the colours visible, the fire was urged till the ladle became red hot, the calcined pellicle upon the surface of the lead was red hot also, but it was still without colour. The same parcel of lead was boiled in a crucible for a confiderable time; during the boiling a copious steam was discharged, and the furface of the lead, as is usual, became covered with a half vitrified scoria. The lead which remained unvitrified was then examined, and it

had

had acquired the property of forming a fuccession of coloured pellicles, during the whole time of continuing in a state of fusion.

Another portion of the same kind of lead was exposed to a strong calcining heat for a long time; the part which remained uncalcined did, at length, acquire the property of exhibiting colours sufficiently vivid.

These experiments induced me to conclude, that the Chinese lead was mixed with some substance from which it was necessary to free it, either by sublimation or calcination, before it would exhibit its colours. It would be useless to mention all the experiments which I made before I discovered the heterogeneous substance with which I supposed the Chinese lead was mixed. At last I hit

hit upon one which seems fully sufficient to explain the phenomenon. Into a ladle full of melted Derbyshire lead, which manifested a succession of the most vivid colours, I put a small portion of tin, and obferved, that as foon as the tin was melted, and mixed with the lead, no more colours were to be feen. I do not know precifely the smallest possible quantity of tin, which will be sufficient to deprive a given quantity of lead of its property of forming coloured pellicles, but I have reason to believe, that it does not exceed one five thousandth part of the weight of the lead.

Derbyshire lead, which has lost its property of exhibiting colours by being mixed with tin, acquires it again, as is mentioned of the Chinese

Q3 lead,

lead, by being exposed to a calcining heat for a sufficient time; the tin, it is supposed, being separated from the lead by calcination, before all the lead is reduced to a calx.

Some calcined Chinese lead was reduced to its metallic form by burning some tallow over it. The reduced lead gave, when melted, coloured pellicles; the calx of tin, which we suppose to have been mixed with the calcined lead, not being so easily reducible as that of lead.

I find that zinc is another metallic substance which has the same property as tin with respect to the depriving lead of its power of forming coloured pellicles; but it does not, I think, possess this power in so eminent a degree as tin. I put small portions of bismuth also into melted

lead, but the lead still retained its quality of forming colours. I melted together some silver and lead, but the lead did not thereby lose its power of forming colours. A little tin added to a mixture of lead and bismuth, or to a mixture of silver and lead, immediately takes away from the respective mixtures the faculty of forming coloured pellicles.

This quality of tin has hitherto, as far as I know, been unobserved; but every new fact, relative to the actions of bodies one upon another, ought to be recorded. The change produced in lead by the admixture of a small portion of tin is much felt by the plumbers, as it makes the metal so hard and harsh, that it is not without difficulty they can cast it into sheet lead. If their old

lead :

lead does not work fo willingly, nor exhibit colours fo readily, as new lead, they may refer the difference to the small quantity of tin contained in the solder, from which old lead can seldom be thoroughly freed.

With respect to the order in which the colours fucceed one another upon the furface of melted lead, it seems to be the following one; yellow, purple, blue, - yellow, purple, green, - pink, green, - pink, green. Upon exhibiting the bright furface of melted lead to the air, I have often observed these ten changes to follow one another in a more or less rapid succession, according to the degree of heat prevailing in the lead. If the heat is but small, the succesfion stops before it has gone through all the changes; but with the greatest heat I did not observe any further variation. All the colours are very vivid, and each seems to go through all the shades belonging to it before it is changed into the next in order.

The formation of these colours may be explained from what has been advanced by Sir Isaac Newton, and illustrated by the very ingenious experiments of Mr. Delaval, relative to the size of the particles constituting coloured bodies.

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## E S S A Y VIII.

Of the smelting of Lead Ore, as practised in Derbyshire.

of perfection in the exercise of every art, which is not always well understood; and after men do sufficiently comprehend it, many ages often pass away before they are fortunate or ingenious enough to attain it. To extract the greatest possible quantity.

quantity of metal, from any particular kind, and any definite quantity of ore, is a problem of great importance, whether it be considered in a philosophical or a commercial light; yet he who should apply himself to the folution of it, with an expectation of being useful to mankind, must take into consideration another circumstance, of as much importance as the quantity of metal to be extracted, - the expence attending the process. For it is obvious, that a great quantity of metal extracted at a great expence, may not produce fo much clear profit, as a less quantity procured at an easier rate; there is a beneficial limit between the quantity to be obtained, and the expence attending the operation, which nothing but experience can ascertain.

It has been proved, by experiments made in France,\* that lead ore when fmelted by a fire made of wood, yielded one tenth more lead, than in the ordinary method of fmelting by means of pitcoal; yet pitcoal is fo much cheaper than wood, in Derbyshire, and most other parts of Great Britain, that the loss of a tenth of the lead, is, probably, more than compensated, by the use of pitcoal instead of wood or charcoal. It is possible, perhaps, even with the use of pitcoal, by an alteration in the process of smelting, to extract from every twenty tons of ore, one ton more of lead than is any where extracted at present; but whether the price of one ton of lead, would be more

<sup>\*</sup> Essais des Mines, par M. Hellot, Vol. II.

more than sufficient to defray the extraordinary expence attending the alteration of the process, must be left to the decision of those who are interested in the success of such inquiries.

The art of fmelting the ores of all metallic substances, was, probably, at first very imperfect in every part of the world; and this doubtless has been a reason, why the use of iron has every where been of a more recent date, than that of the other metals, since it requires the application of a much stronger sire to smelt the ores of iron, than those of any other metal.

We have no certain account when, or by whom, the several metals were discovered; Wallerius says, that, as far as he knew, Pliny was the first who

who enumerated the fix metals: + Pliny may, probably, be the first Natural Historian who mentioned them, but they were certainly known long before the age of Pliny, and were mentioned both by Homer, and by an author far more ancient than Homer - Moses. - " Only the gold, and the filver, the brass (copper), the iron, the tin, and the lead, every thing that may abide the fire, ye shall make it go through the fire, and it shall be clean." † From this testimony we are certain that all the metals were known, at least in the country of the Midianites, above 1450 years before the birth of Christ, or near 900 years after

<sup>+ —</sup> Primus (scil. Plinius) quantum mihi constat, sex metalla enumeravit. Waller. de Sys. Minera. p. 10.

<sup>1</sup> Num. xxxi. 22.

after the deluge. When I say all the metals, I must be understood to mean, all those which were anciently known; for platina, the seventh metal, has been but recently discovered, and is not yet brought into general use; and quicksilver or mercury is not admitted by mineralogists into the class of metals; though it has a good right to be admitted, fince in a sufficient degree of cold, it possesses the great characteristic property of a metal, as distinguished from a semimetal - malleability. This property of malleability, as constituting the criterion by which metals differ from femimetals, is not over rigidly to be infifted on, fince iron, when first fluxed from its ore, or when converted into fteel, and hardened by being fuddenly immerfed when red hor

hot in water, is less malleable than zinc, which is always classed amongst the semimetals.

It has been contended, that copper was one of the first metals which was used as money, and that gold and filver were, in very remote ages, of little account in that view. In many instances the greatness of the Roman name has made us forget the æra when that people began to be distinguished in history, and induced us to consider their customs, as the first which prevailed amongst mankind. It is granted, that Servius Tullius first coined copper, and that the Romans used no other currency till the four hundredth and eightyfifth year of their city,\* when filver began to be coined; but from this

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<sup>\*</sup> Plin. Hist. Nat. Lib. XXXIII. S. 13. VOL. III. R

concession, no argument can be deduced for the fole use of copper as a currency, in the first ages of the world. We know, from undoubted authority, that filver was used in commerce, at least eleven hundred years before even the foundation of Rome. — And Abraham weighed to Ephron, the filver which he had named in the audience of the sons of Heth, four hundred shekels of silver, current money with the merchant.\* About 60 years before Abraham paid this fum for a piece of land in Canaan, he is faid, upon his return from Egypt, to have been rich, not in copper and iron, but in filver and gold. +

Iron and copper were certainly known before the deluge; and it is probable, that all the other metals,

every

<sup>\*</sup> Gen. xxiii. 16. + Gen. xiii. 2.

every one of which is more easily extracted from its ore than iron and copper are from theirs, were known also to the Antediluvians; we have proof, however, that in the time of Abraham, gold and filver were esteemed, as they are at present, precious metals; and hence it feems reasonable enough to conclude, that Noah was able to instruct his descendants in the art of smelting metallic ores: but, though this be admitted, we need not be furprized at the ignorance of many barbarous nations in this particular. For the various colonies which, either by compulsion or choice, quitted the plains of Asia in search of settlements, may not always have had in their company, men who had been instructed in the art of fmelting; and those who R 2 did

did understand it, when the colony first migrated, may, in many instances, have died before any ores were discovered, upon which they might have exerted their skill; and thus the art of smelting being once lost, it is easy to conceive that many nations may have remained for ages without the use of metals, or with the use of such only as are found ready formed in the earth, or are easily fluxed from their ores.

The earth in a little time after the deluge, and long before it could have been peopled by the posterity of Noah, must have become covered with wood. The most obvious method of clearing a country of its wood, is the setting it on fire; now in most mineral countries there are veins of metallic ores, which lie contiguous to the furface of the earth, and these having been fluxed whilst the woods growing over them were on fire, probably, suggested to many nations the first idea of smelting ores.

— Pow'rful gold first raised his head,
And brass, and filver, and ignoble lead
When shadywoods, on losty mountains grown
Felt scorching fires; whether from thunder
thrown

Or else by man's design the slames arose.

Whatever 'twas that gave these flames their birth,

Which burnt the towering trees and fcorch'd the earth,

Hot streams of filver, gold, and lead, and brass (copper)

As nature gave a hollow proper place Descended down, and form'd a glitt'ring mass.\*\*

There.

<sup>\*</sup> Lucretius by Creech. Vol. II. p. 572.

There is no natural absurdity in this notion of the poet; and indeed it is confirmed by the testimony of various ancient historians, who speak of filver and other metals being melted out of the earth, during the burning of the woods upon the Alps, and the Pyrenees. A similar circumstance is said to have happened in Croatia in the year 1761; a large mass of a mixed metal, composed of copper, iron, tin and filver, having been fluxed, during the conflagration of a wood, which was accidentally fet on fire. \*

The putting a quantity of ore upon a heap of wood, and fetting the pile on fire, in conformity to the manner in which ores were smelted during the burning of forests, was,

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<sup>\*</sup> Annual Register, 1761. p. 138.

it may be conjectured, the first rude process by which metals were extracted from their ores. But as the force of fire is greatly diminished, when the flame is fuffered to expand itself, and as the air acts more forcibly in exciting fire; when it rushes upon it with greater velocity, it is likely, that the heap of wood and ore would foon be furrounded with a wall of ftone, in which fufficient openings would be left for the entrance of the air, and thus a kind of furnace would be constructed. The Peruvians we are told "had discovered the art of fmelting and refining filver, either by the simple application of fire, or where the ore was more stubborn and impregnated with foreign substances, by placing it in small ovens or furnaces on high

R.4 grounds

grounds, fo artificially constructed that the draught of air performed the function of a bellows, a machine with which they were totally unacquainted."

This method of finelting ores on high grounds, without the affiftance of a bellows, at least of a bellows moved by water, feems to have been formerly practifed in other countries as well as in Peru. When M. Belon travelled into Greece, he found the furnaces placed on the fides of rivulets, and observes, that all their bellows played with wheels turned by streams of water, yet formerly they had smelted their ores in a different manner: for upon the mountains

<sup>\*</sup> Robertson's Hist. of America. — Alonson Barba, Treatise of Metals, French Trans. Vol. I. p. 272.

tains of Macedonia, where mines ha been wrought in the time of Philip the father of Alexander, great heaps of flag have been discovered, which are fituated fo far above any river of the country, that the furnaces from which they were formed, must, probably, have been wrought by the wind. There are feveral places in. Derbyshire called Boles by the inhabitants, where lead has been anciently fmelted, before the invention of moving bellows by water. Thefeplaces are discovered by the slags of lead, which are found near them; there is no certain tradition concerning the manner in which the ore was smelted at these boles, it was, probably, as simple as that of the Peruvians, for in Derbyshire, as well: as in Peru, they feem chiefly to have relied

relied upon the strength of the wind for the fuccess of the operation; the boles being always situated upon high grounds, and mostly upon that side of a hill, which faces the west. This situation was not fixed upon without defign, fince the wind blows in England, in the course of a year, near twice as many days from that quarter as from any other.\* A method is mentioned by Erckern + of fmelting bismuth ore by the wind, and it feems as if the ore of lead might have been smelted at these boles.

\* As may appear from the following abridged state of the winds at London in the years 1774 and 1775.

Philof. Trans. 1774 - 5.

+ See Fleta Minor. by Sir John Pettus.
p. 303.

boles, after the same manner. This method confifts in putting the bifmuth ore, when beat to a proper fize, into fmall flat iron pans, these are fet in a row contiguous to each other, in an open place; and when there is a strong wind, a fire of dry wood is made close to the pans, and on that fide of them from which the wind blows, by this contrivance, the wind driving down the flame of the wood upon the pans, the ore contained in them is quickly melted. A pig of lead was dug up at one of the boles in the year 1766 on Cromford moor near Matlock, upon its under surface there is an inscription in relievo, from which it appears to have been smelted in the age of the Emperor Adrian; it is not very different in shape from the pigs which are

are cast at present; it consists of several horizontal layers of unequal thicknesses, and there is an irregular hole in it, running from the top to near the middle of its substance, from these appearances it seems as if it had been formed by pouring into a mould, at different times, feveral quantities of lead; and if lead had been smelted after the manner before mentioned of fmelting bismuth ore, the feveral pans being emptied, at different times as they became ready, into the same mould, would have yielded a mass of lead divided into layers of unequal thicknesses, and resembling this Roman pig; for the hole in its furface was, probably, made accidentally, from the unequal cooling of the lead, or from some extraneous matter being lodged in it.

The

The boles in Derbyshire are, probably, many of them of high antiquity, as appears from the pig of lead before mentioned; yet I have met with a passage in a writer of the last century, from which it is evident, that the method of fmelting lead on high grounds was then practifed in the Peak. "The lead-stones in the Peak lye but just within the ground next to the upper crust of the earth. They melt the lead upon the top of the hills that lye open to the west wind; making their fires to melt it as foon as the west wind begins to blow; which wind by long experience they find holds longest of all others. But for what reason I know not, fince I should think lead were the easiest of all metals to melt, they they make their fires extraordinary great."\*

The fmelting of ore by the variable and uncertain action of the wind, must have been a troublesome procefs, it has therefore been univerfally difused, and the more regular blast of a bellows has been introduced in its stead. The invention of . the bellows is attributed by Strabo to Anacharsis the Scythian; † but it is more probable, that he was the inventor of some improvement of this machine, than of the machine itself; for Homer, who lived long before the age of Anacharsis, describes Vulcan as employing twenty pair of bellows at once, in the formation of Achilles' shield.

<sup>\*</sup> Childrey's Britan. Bacon. 1661.

t Strab. Geog. Lib. VII.

fhield. + It is difficult to fay when the art of moving bellows, by means of a water wheel, was first discovered; it is pretty certain, that the ancients did not know it; and that it was very generally known, amongst the Germans at least, in the time of Agricola, one of the first of our metallurgic writers, for he speaks of it in feveral places without any hint of its being a recent invention. ‡ The heat of the fire in a furnace depending much upon the force of the blast of air impelled against the fuel; and that force, other circumstances remaining the fame, being in proportion to the quantity and velocity of the air; the application of a power able

<sup>†</sup> Iliad. Lib. XVIII. v. 470.

<sup>†</sup> Agric. de Re Metal. published in 1550, p. 165. 338.

able fuddenly to compress the largest bellows when swelled with air, could not fail of being considered by metallurgists, as an invention, whenever it was made, of the last importance. The moderns accordingly have, in many instances, worked over again, with considerable profit, the heaps of iron and other kinds of slag, from which the metal had been but imperfectly extracted, before the moving of bellows by water was discovered.

It is not fifty years fince the blast or hearth furnace, was the only one in use for smelting lead ore in Derbyshire. In this furnace ore and charcoal, or ore and what they call white coal, which is wood dried but not charred, being placed in alternate layers, upon a hearth properly

constructed, the fire is raised by the blast of a bellows, moved by a water wheel; the ore is foon fmelted by the violence of the fire, and the lead as it is produced trickles down a proper channel, into a place contrived for its reception. There are not at present, I believe, above one or two of these ore hearths in the whole county of Derby; this kind of furnace, however, is not likely to go entirely out of use, since it is frequently applied to the extracting lead from the flag which is produced, either at the ore hearth, or the cupola furnace, and it is then called a flag hearth; and the lead thus obtained is called flag lead: the fire in a flag hearth is made of the cinder of pitcoal instead of charcoal.

The furnace called a cupol or cuvol, III. S pola pola, in which ores are fmelted by the flame of pitcoal, is faid to have been invented, about the year 1698, by a physician named Wright, \* though Beecher may, perhaps, be thought to have a prior claim to its. invention or introduction from Germany. + But whoever was the first: inventor of the cupola, it is now in general use, not only in Derbyshire: and other countries for the smelting; of the ores of lead, but both at home and abroad, where it is called the English furnace, for the smelting of copper ores. This furnace is focontrived, that the ore is melted, not: by coming into immediate contact: with the fuel, but by the reverberation of the flame upon it. The bottom of the furnace on which the lead

<sup>\*</sup> Essais des Mines, Vol. II. p. 114. + See Vol. I. p. 33.

lead ore is placed, is somewhat concave, shelving from the sides towards the middle; its roof is low and arched, refembling the roof of a baker's oven; the fire is placed at one end of the furnace, upon an iron grate, to the bottom of which the air has free access; at the other end, oppofite to the fire place, is a high perpendicular chimney; the direction of the flame, when all the apertures in the fides of the furnace are closed up, is necessarily determined, by the stream of air which enters at the grate, towards the chimney, and in tending thither it strikes upon the roof of the furnace, and being reverberated from thence upon the ore it foon melts it.

It is not always an easy matter to meet with a current of water, suffi-

cient

cient to move the bellows required in fmelting on an hearth furnace; and to carry the ore from the mine where it is dug, to a confiderable distance to be smelted, is attended with great expence; this expence is faved by fmelting in the cupola furnace, which not requiring the use of bellows, may be constructed any where. - Wood is very scarce in every mining country in England, and though pitcoal costs ten or twelve shillings a ton in Derbyshire, yet they can fmelt a definite quantity of ore in the cupola, at a far less expence by means of pitcoal, than of wood. - The flame which plays upon the furface of the ore and smelts it in a cupola furnace, is not driven cagainst it with much violence; by this means small particles of ore, called 1 3

called belland, may be smelted in a cupola furnace with great convenience, which would be driven away, if exposed to the fierce blast of a pair of bellows in a hearth furnace. - These are some of the advantages attending the use of a cupola in preference to a hearth furnace, and to these may be added one superior to all the rest, - the preservation of the workmen's lives; the noxious particles of lead are carried up the chimney in a cupola, whilst they are driven in the face of the hearth fmelter at every blaft of the bellows.

They generally put into the cupola furnace a ton of ore, previously beat small and properly dressed, at one time; this quantity they call a charge; if the ore is very poor in lead they put in somewhat more, and they

work off three charges of ore in every twenty-four hours. In about fix hours from the time of charging, the ore becomes as fluid as milk. Before the ore becomes fluid, and even whilst it continues in a state of fusion, a considerable portion of its weight is carried off through the chimney; what remains in the furnace confifts of two different substances, - of the lead, for the obtaining of which the process was commenced, - and of the flag or scoria. The proportion between these parts is not always the fame, even in the fame kind of ore; it depending much upon the management of the fire. The lead, being heavier than the flag, finks through it as it is formed, and fettles into the concavity of the bottom of the furnace. The pure .. flag,

Mag, according to the idea here given, is that part of the ore of lead which is neither driven off by the heat of the furnace, nor changed into lead. In order to obtain the lead free from the flag which swims over it, the fmelters usually throw in about a bushel of lime, not, as is usually supposed, in order to contribute towards the more perfect fufion of the ore, but to dry up the flag which floats upon the furface of the lead, and which, being as liquid as lead, might otherwise flow out along with it. The flag being thus thickened by an admixture of lime, is raked up towards the fides of the furnace, and the lead is left at the bottom. There is a hole in one of the fides of the furnace, which is properly Ropped during the fmelting

of

of the ore; when the slag is raked off, this hole is opened, and being situated lower than the lead in the furnace, the lead gushes through it into an iron pot placed contiguous to the fide of the furnace; from this pot it is laded into iron moulds, each containing what they call a pig of lead, the pigs when cold being ordinarily stamped with the maker's name, are fold under the name of ore lead. After the lead has all flowed out of the furnace, they stop up the tap hole, and drawing down the flag and lime into the middle of the furnace, they raise the fire till the mixture of flag and lime, which they fimply term flag, is rendered very liquid, upon this liquid mass they throw another quantity of lime to dry it up as in the former part of the process.

cess. This second mixture of slag and lime is then raked out of the furnace, and the small portion of lead feparated from the fusion of the first, generally to the amount of twenty or thirty pounds, being let out of the furnace, a new charge of ore is put in, and the operation re-commenced. In order to spare the lime, and the expence of fuel attending the fluxing of the mixture of lime and flag, they have in some furnaces lately contrived a hole, through which they fuffer the main part of the liquid flag to flow out, before they tap the furnace for the lead; upon the little remaining flag they throw a fmall portion of lime, and draw the mixture out of the furnace without smelting it. This kind of furnace they have nick-named a Maccaroni.

The process of smelting here described, appears to be desective in some points, which I will take the liberty to mention, and at the same time suggest the means of improvement; without, however, presuming to say, how far it may be expedient to adopt the proposed alterations; being sensible that what may appear very feasible in theory, or may even answer in small assays, may not be practicable in large works.

The first alteration which I would propose to the consideration of the lead smelters, is to substitute an horizontal chimney of two or three hundred yards in length, in the place of the perpendicular one now in use.

In the preceding Essay, which was first published in 1778, mention is made of the probability of faving a large quantity of fublimed lead, by making the smoke, which rises from the ore, pass through an horizontal chimney, with various windings to condense the vapour. I have since conversed with some of the principal lead smelters in Derbyshire, and find that I had over-rated the quantity of this sublimed lead; the weight of the scoria from a ton of ore, amounting to more than I had supposed; they were all of them, however, of opinion, that the plan I had proposed for faving the sublimate, was a very rational one. But so difficult is it to wean artists from their ancient ways of operating, that I question very much whether any of them

them would ever have adopted the plan they approved, if an horizontal chimney which was built a little time ago, in Middleton dale for a quite different purpose, had not given them a full proof of the practicability of faving the sublimate of lead, which is lost in the ordinary method of finelting. This chimney was built on the fide of an hill, to prevent fome adjoining pastures from being injured by the smoke of the furnace. It not only answers that end, but it is found also to collect considerable quantities of the lead, which is fublimed during the smelting of the ore; this sublimed lead is of a whitish cast, and is fold to the painters at ten or twelve pounds a ton; it might perhaps be converted into red lead with still more profit.

A se-

· A fecond circumstance to be attended to in the smelting of lead ore, is the faving the fulphur contained in it. The pure lead ore of Derbyshire contains, between an eighth and a ninth part of its weight of fulphur; but as the ore which is fmelted is never pure, being mixed with particles of spar, cawk, limestone, brazil and other substances, which the miners call deads, we shall be high enough in our supposition, if we say that the ordinary ore contains à tenth of its weight of sulphur; it may not, probably, contain so much, but even a twelfth part, could it be collected at a fmall expence, would be an object of great importance to the fmelter. In the common method of fmelting lead ore there is no appearance of the fulphur it contains,

it is confumed by the flame of the furnace, as foon as it is separated from the ore; an attentive observer may, indeed, by looking into the furnace distinguish a diversity in the colour of the flame, at different periods of the process; during the first three or four hours after the ore is put into the furnace, the flame has a bluish tint, proceeding no doubt from the fulphur which, in being sublimed from the ore, is inflamed: after all the fulphur is feparated from the ore, the flame has a whitish cast, and then and not before the fire may be raifed for finishing the operation; for if the fire be made strong before the sulphur be dispersed, the quantity of lead is less, probably, for two reasons; the sulphur unites itself in part to the lead which.

is formed, and by this union becomes inseparable from it; for the fulphur cannot without much difficulty be separated from an artificial mixture of lead and fulphur, when the two ingredients have been fused together; - 2. The fulphur whilst it continues united to the lead in the natural ore, renders the ore volatile, fo that in a strong heat a great portion of it is driven off. Hence, very fulphureous ores should be roasted for a long time with a gentle hear, and in this proper management of the fire, principally confifts the fuperiority of one fmelter above another.

An old lead smelter informed methat he had often reduced a ton of ore to 16 hundred weight by roasting it, but that he did not obtain

more metal from it by a subsequent fusion, than if he had fluxed it without a previous roafting. This may be true of some forts of ore, but it is not true of very sulphureous ores. Indeed the fire may be fo regulated in a cupola furnace, as to make it answer the purpose of a roasting and a fmelting furnace at the fame time: I have feen much lead loft by fmelting a ton of fulphureous ore in eight hours, which might have been faved, if the fire had at first been kept so gentle as to have allowed twelve hours for finishing the operation.

Sulphur cannot be separated from lead ore in close vessels, and the lead ore melts with so small a degree of heat, that there may be more difficulty in procuring the sulphur from the ores of lead, than from those of

copper

copper or iron, however I am far from thinking the matter impracticable, though I have not yet hit upon the method of doing it; and the following reflections may, perhaps, tend to superfede the necessity of collecting the sulphur in substance.

When it is faid that the fulphur is confumed by the flame of the furnace as foon as it is separated from the ore, the reader will please to recollect, that sulphur consists of two parts, - of an inflammable part by which it is rendered combustible, - and of an acid part which is fet at liberty, in the form of vapour, during the burning of the fulphur. Now this acid, though it may be driven out of the furnace in the form of a vapour, yet it is incapable of being thereby decomposed; it still VOL. III. con-

continues to be an acid, and, could the vapour be condenfed, might anfwer all the same purposes as the acid of vitriol; fince all the acid of vitriol, now used in commerce, is actually procured from the burning of fulphur. That the fact, with respect to the acid not being decomposed is as I have stated it, may be readily proved. The smoke which issues out of the chimney for some hours after each fresh charge of ore, has a fuffocating smell, perfectly refembling the fmell of burning brimstone, and if a wet cloth, or a wet hand be held in it for a very short space of time, and afterwards applied to the tongue, a strong acid will be fenfily perceived. Various methods may be invented for condenfing this acid vapour, and, probably,

more commodious than the following one, which, however, I will just take the liberty of mentioning, as, if it should not succeed, the trial will be attended with very little expence.

Supposing then an horizontal chimney to be built, let the end farthest from the fire be turned up by a tube of earthen ware, or otherwise, fo that the fulphureous acid may issue out in a direction parallel to the flue of the chimney, and at the diftance of about a foot and an half above it. Let a number of large globular vessels be made of either glass or lead; each of these globes must have two necks so as to be capable of being inferted into one another, let these vessels be placed on the flue of the chimney, the neck of the first being inserted into

the tube through which we have supposed the sulphureous acid to issue, and the neck of the last being left open, for fear of injuring the draught of the furnace. Let each of these globular vessels contain a small quantity of water, then it is conceived, that the heat of the flue will raise the water into vapour, and that this watery vapour will be the means of condensing the sulphureous acid vapour, if not wholly, at least in fuch a degree as may render the undertaking profitable. When the fulphur is all confumed, the draught of the furnace may be suffered to have its ordinary exit at the end of the horizontal chimney, by a very flight contrivance of a moveable damper. Since the first publication of the preceding Essay, I have seen

an horizontal chimney at the copper works near Liverpool, where every thing I had faid concerning the probability of faving fulphur by roafting lead ore, is verified with respect to copper ore: and I believe a patent has been granted to some individual for this mode of collecting fulphur. Sulphur might be obtained with equal facility from the pyrites which is found amongst coal, and this application of the pyrites might, probably, be more lucrative than the present one - making green vitriol\*.

A third circumstance which requires the utmost care of the lead smelter, is the leaving as little lead as possible in the slag. Near every simulating house there are thousands of tons of slag, which, when properly

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affayed.

<sup>\*</sup> Vol. I. p. 226.

affayed, are found to yield from one eighth to one tenth of their weight of lead; though no person has yet discovered a method of extracting so much from them when smelted in large quantities; and indeed the fmelters are fo little able to obtain all the lead contained in them, that in many places they never attempt to extract any part of it: in some places, where they do attempt it, I have known the proprietor of the slag allow the smelters 20 s. for every pig of lead they procured of the value of 38s. besides furnishing them with fuel; and yet the men employed in fuch an unwholesome business, feldom made above 7 s. a week of their labour. This fusion of the flag of a cupola furnace is made, as has been mentioned, at a hearth fur-

nace; the coal cinder which they use as fuel, and the flag are foon melted by the strong blast of the bellows. into a black mass, which, when the fire is very strong, becomes a perfect glass; this black mass, even in its most liquid state, is very tenacious, and hinders many of the particles of lead from fubliding, and it being from time to time removed from the furnace, a considerable quantity of lead is left in it, and thereby loft. A principal part of the lead contained in the flag of the cupola furnace, is not, I apprehend, in the form of a metal, but in the form of a litharge or calcined lead: a portion: of the lead, in being smelted from its ore, is calcined by the violence of the fire; this calcined lead is not only very vitrifiable of itself, but it

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helps

helps to vitrify the spar which is mixed with the ore, and thus constitutes the liquid scoria; might it not be useful to throw a quantity of charcoal dust upon the liquid scoria in the cupola furnace, in order that the calcined lead might be converted into lead, by uniting itself to the inflammable principle of the charcoal? - Iron will not unite with lead, but it readily unites with fulphur, and when added to a mixture of lead and fulphur, it will absorb the fulphur, leaving the lead in its metallic form; might it not be useful to flux fulphureous lead ores in conjunction with the scales or other refuse pieces of iron, or even with fome forts of iron ore? - The fmelter's great care should be to extract as much lead as possible at the first 

first operation of smelting the ore, and to leave the flag as poor as poffible; but if he should still find either the flag of the cupola furnace, or that of the hearth furnace, containing much lead, (as that even of the hearth furnace certainly does), he may, perhaps, find it worth his while to reduce the flag into a powder by a stamping mill, or by laying it in highways to be ground by the carts, or by some other contrivance, and then he may separate the stony part of the flag from the metallic, by washing the whole in water, inasmuch as the metallic part is far heavier than the other.

I estimated the weights of several pieces of slag, and found them to differ very much from each other; this difference is principally to be

attributed to the different quantities of lead left in them.

Weight of	a cubic f	oot of			
			- 1	Avoir. oz.	
Slag from a cup no lime was	oola furn	ace, v	where	3742	
Black flag from	a hearth	furna	ce -	3652	
Another piece	-	•		3612	
Black flag from	another	hearth	fur-	2228	
Black flag from another hearth fur- nace — ftruck fire with fleel 33378					
Black glass slag		-	-	3371	

This may not be an improper place to add a word or two concerning the Derbyshire Toadstone, which constitutes one of the principal strata in the mining country,\* and which is supposed to have been in its origina slag thrown out by a volcano. It perfectly resembles some of the specimens, I have seen, of one of the sorts of the lava of Vesuvius, not only in

<sup>\*</sup> See Vol. II. p. 206.

in the hardness of its texture, and blackness of its colour, but in itsweight; a cubic foot of some sorts of Derbyshire toadstone weighing more, and of other less than a cubic foot of the Vesuvian lava, which it resembles. The streets of London have some of them been paved, of late years, with a toadstone from Scotland, of the same nature as the Derbyshire toadstone; and the streets of Naples have for many centuries past, been paved with the lava from Vefuvius which refembles toadstone. Neither the Derbyshire toadstone, nor that fort of Vesuvian lava which resembles it, seem to have experienced in their formation any great degree of heat, they are but in a half vitrified state; the toadstone I have frequently melted in a smith's forge into

into a black glass, and the Vesuvian lava gives a glass of the same kind. The air has a manifest action upon the Derbyshire toadstone, for it not only wastes away the spar which is found in the blebs of some sorts of toadstone, but it reduces into a brownish mould, sit for vegetation, the most hard and compact sorts; the Vesuvian lava is subject to the same change from the operation of the same cause.

Weight of a cubic foot of	
	Avoir.oz
Toadstone hard and free from blebs	2884
Vesuvian lava resembling toadstone	2865
Iron slag, a greenish glass	2843
Iron slag, a brownish glass	2729
Iceland crystal — Mr. Cotes	2720
Toadstone, decaying	2680
A.,	2662
Another piece	2558

ESSAY



## ESSAY IX.

Of Silver extracted from Lead.

Perly speaking, in great Britain, but we have plenty of lead, from which silver is, in some places, extracted with much profit. If the method of doing this had been known to the ancient Britans, it might have freed our country from the reproach of Cicero, who tells his friend Atticus, that there was not a scruple of silver

in

in the whole island; \* and in another place, he fays, that he had heard there was neither gold nor filver in Britain. + The Romans had a very imperfect knowledge of this country in the time of Cicero, fo that his account of the matter may not, perhaps, deserve to be much relied on; we are certain, at least, that about fifty or fixty years afterwards, both gold and filver were reckoned by Strabo amongst the products of Britain; I hence if the Britons did not understand the art of extracting silver from lead at the first invasion of the

<sup>\* —</sup> etiam illud jam cognitum est, neque argenti scrupulum esse ullum in illa infula (Britann). Epist. ad Att. L.IV. E.XVII.

<sup>+</sup> Epist. Fam. L. VII. E. VII.

<sup>‡</sup> L. IV. p. 305. — See also Tacitus' Life of Agicola.

from their conquerors, and this becomes more probable, if it be admitted, that filver was coined in Britain in the time of Augustus.\*

Silver is so commonly contained in lead, that it is esteemed a very great curiosity to meet with lead which is entirely free from it: it has even been afferted, that there is no lead in the world, except that of Villach in Carinthia, which does not contain filver. †

The more ancient alchemists, not knowing, probably, that silver was so generally contained in lead, and yet

\* Sir John Pettus Fod. Reg.

† Il n'y point de plomb au monde, hormis celui de Villach que ne contienne de l'argent. Lehman sur les Mines, Vol. I. p. 174. — See also Philos. Trans. for 1665. p. 10,

yet observing, that lead, when treated according to their processes, often gave a portion of silver, were of opinion, that they could convert lead into silver.\* This was an easy mistake, and if they had obtained a portion of gold, they would, no doubt, have concluded, that they had transmuted the lead into gold; since there is no metal, perhaps, which does not contain a small quantity of gold, or from which gold may not be separated by long calcination.

Lister had long ago observed, that all the English lead contained silver; and he speaks as having, by his own experiments, proved the existence of silver in the lead of at least thirty different mines; † nor has any per-

fon

<sup>\*</sup> Gebri Chem. L. I. C. XIX.

<sup>+</sup> Lister de Fontibus, Cap. II. S. 9, 10.

fon fince his time found lead wholly free from filver. The Derbyshire lead has been faid to contain two grains of filver in a pound of lead. \* Every general observation of this kind is liable to much contravention from particular facts; because the quantity of filver contained in lead, is not only different according as the lead is fluxed from the ore of different mines, but it is very possible in an affay of the ore of the same mine, to meet with one piece of ore which shall afford a lead yielding eight or ten times as much filver, as another piece would do. This diversity arises from the ore itself being variable in quality in different parts of the same mine; and even different lumps of ore, though contiguous to each other,

will

<sup>\*</sup> Oper. Min. Explicata, p. 263.

will often yield very different quantities of filver, from the same quantity of lead. This observation may explain the reason of the very opposite testimonies, which have been sometimes given in courts of justice, concerning the richness of a mine from particular affays; the plaintiffs and defendants, where the iffue to be tried was the quantity of filver, having been feverally interested in getting the best and the worst pieces of ore affayed, in order to support their respective claims. There was a notable instance of this with respect to the lead mine of Est-kyr-kyr in Cardiganshire, which was discovered in 1690. The law at that time adjudged every mine to be a royal mine, the metal of which contained enough of gold or filver to compensate the charges

charges of refining, and the loss of the baser metal in which they were contained. In consequence of this law the patentees of royal mines laid claim to the mine of Est-kyr-kyr which was rich in silver, and they produced proof in Westminster-hall, that the lead of that mine contained to the value of sixty pounds of silver in every ton, whilst the proprietor produced proof that it only contained to the value of four pounds of silver in a ton. \*

I have been informed by an intelligent person, that there are some lead ores in Great Britain, which, though very poor in lead, contain between three and sour hundred ounces of silver in a ton of the lead. It is not to be expected that the proprietors

<sup>\*</sup> Some account of Mines. p. 27.

prietors of these, or of any other mines rich in filver, should be forward in declaring to the world the quantity of filver which they contain. The proprietor indeed of a lead mine containing filver, may work the same, without any apprehension of its being taken from him, under the pretence of its being a royal mine; yet the crown, and perfons claiming under it, have the right of pre-emption, of all the ore which may be raised. There was an act of parliament passed in the sixth year of William and Mary intitled, - An act to prevent disputes and controversies concerning royal mines. -This act gave great quiet to the fubject by declaring, that every proprietor of a mine of copper, tin, iron, or lead, should continue in possession of the faid mine, notwithstanding its being claimed as a royal mine, from its containing gold or filver: but it further enacted, that their majesties, their heirs and fucceffors, and all claiming under them, should have the privilege of purchasing all the ore which should be raised out of fuch a mine, at the following prices; that is to fay, paying for all ore washed, made clean and merchantable, wherein is copper, after the rate of fixteen pounds a ton, for tin ore (except that raised in Devonshire and Cornwall) forty shillings, for iron ore forty shillings, and for lead ore nine pounds a ton. This standard price of nine pounds a ton for lead ore was, at the time it was fixed, much higher than the ordinary price of ore, in which there was no filver U 3

filver worth extracting; the best kind of Derbyshire lead ore, being, at present, generally worth not more than feven pounds a ton. It may deferve however the confideration of the legislature, whether the clause in the forementioned act respecting the right of pre-emption should not be wholly repealed; as there may be many lead mines in England very rich in silver, but which, on account of the difficulty of working them, cannot be entered upon with advantage, whilft this right subsists. At many lead mines, moreover, there are large quantities of steel-grained ore raised together with the ordinary, fort, now it generally happens that the steel-grained ore is much richer in filver than the ordinary diced ore of Derbyshire; and it might, if sepa-

rated.

rated from the rest, be worked for silver; but whether from an apprehension of the operation of the clause we are speaking of, or from mere ignorance or inattention, all the forts of ore are mixed and smelted together.

Silver has formerly been extracted a from lead in a great many places in this island. In the reign of Edward I, near 1600 pounds weight was obtained, in the course of three years, from a mine in *Devonshire*, which had been discovered towards the beginning of his reign; this mine is called a silver mine by the old writers, but it appears to have been a mine of lead which contained silver.\* The

<sup>\*</sup> Hollingshed's Chron. Vol. II. p. 316.

lead mines in Cardiganshire have at different periods afforded great quantities of silver: Sir Hugh Middleton is said to have cleared from them two thousand pounds a month, \* and to have been enabled thereby to undertake the great work of bringing the new river from Ware to London; and in allusion, probably, to these two great circumstances of his life, there are painted upon some of his pictures the two terms - fontes - fodinæ. These same mines yielded, in the time of the great rebellion eighty ounces of filver out of every ton of lead, and part of the king's army was paid with this filver which

was

of filver extracted from lead in Devonshire and Cornwall in the time of Edward III. P. 413.

<sup>\*</sup> Oper. Min. explic. p. 245.

was minted at Shrewsbury. + A mint for the coinage of Welch filver had before that time been established in 1637 at Aberystwith; the indenture was granted to Thomas Bushel for the coining of half crowns, shillings, fix-pences, two-pences, and pennies, and the monies were to be stamped with the offrich feathers on both fides \*. In the year 1704 near three thousand ounces of this Welch bullion were minted, at one time, at the tower t. Webster in his history of metals, published in 1671, makes mention, from his own knowledge, of two places in Craven, in the westriding of Yorkshire, where formerly good filver ore (lead ore abounding in

<sup>+</sup> Sir J. Pettus, Essay on Metal. Words.

Rym. Fæd. Tom. XX. 164.

<sup>1</sup> Some account of mines. p. 6.

in filver) had been gotten. One of the places was Brunghill moor in the parish of Slaidburn, the ore of which held about the value of fixty seven pounds of silver in a ton: the other was Skelkorn field within the township of Rimmington in the parish of Gisburn; it had formerly belonged to one Pudsey, who is supposed to have coined the silver he got out of his mine, there being many shillings in that country which the common people called Pudsey's shillings.\*

There is not at present any place in Derbyshire where silver is extracted from lead. A work of this kind was established a few years ago not far from Matlock, and the lead yielded fourteen ounces of silver from a ton; but the mine which afforded the

<sup>\*</sup> Webster's Metal. p. 21.

the ore was foon exhausted, or became too difficult to be worked with profit. There is a lead mine in Patterdale near Keswick, which yields between fifty and sixty ounces of silver from a ton of the lead; the ore of this mine is reckoned to be poor in lead; and indeed it is very commonly observed, that the poorest lead ores yield the most silver, so that much silver is probably thrown away, for want of having the ores of the poorest fort properly assayed.

The quantity of lead smelted annually in Derbyshire, may be estimated at 7500 tons upon an average; sifty years ago the average was, probably, 10000 tons a year, but we put it high enough in supposing it, at present, to amount to 7500 tons: I have never been able to get any proper

proper information, concerning the quantity of lead annually smelted in other parts of Great Britain, but for the illustration of the subject we are upon, let us suppose that in the whole kingdom 30000 tons of lead are annually fmelted, and that at a medium each ton of lead would yield 12 ounces of filver, then would there be, if all the lead was refined, a faving of three ounces of filver from each ton of lead, or ninety thoufand ounces in the whole; our English workmen reckoning that nine ounces of filver are fully adequate to the expence of refining a ton of lead, added to that of the lead which is lost during the operation.

The general manner of extracting filver from lead is every where the fame; it is very fimple, depending upon

upon the different essential properties of the two metals. - It is an effential property of lead, when melted in the open air, to lose its metallic appearance, and to burn away into a kind of earth. - It is an effential property of filver, not to burn away, or to lose its metallic appearance when exposed to the action of the strongest fires, in the open air. Hence, when a mass of metal confifting of lead and filver, is melted in the open air, the lead will be burned to ashes, and the silver remaining unaltered, it is easy to understand how the filver may be extracted from the lead, for being heavier than the ashes of the lead, and incapable of mixing with them, (fince no metal is miscible with an earth), it will fink to the bottom of the

the vessel in which the mass is melted. Iron, tin, and copper, resemble lead, in being convertible into a kind of ashes, when exposed to the action of air and fire, and gold refembles filver in not undergoing any change from such action; hence either gold or filver, or a mass confifting of both, may be purified from any or all of these metals by the mere operation of fusion; for these metals will rife to the top of the veffel, in which the fusion is made, in the form of earth or drofs, leaving the gold or filver pure at the bottom.

The ancients certainly knew that filver could be purified from the base metals by the force of fire.—

The house of Israel is to me become dross: all they are brass, (copper) and

Lin, and iron, and lead, in the midst of the furnace; they are even the dross of filver.\* And as we read of filver being purified seven times in a furnace of earth, + it may, perhaps, be inferred, that the method of refining filver which was then in use, confifted in reducing the base metals into earth, by a repetition of the process of fusion. This inference, it must be owned, is rendered doubtful by a passage in Feremiah; - the bellows are burned, the lead is consumed of the fire, the founder melteth in vain I - This paffage is fomewhat ambiguous, and interpreters translate the original Hebrew differently, but most of them collect from it, that the founder

<sup>\*</sup> Ezek. xxii. 18. + Pf. xii. 6.

<sup>1</sup> Jerem. vi. 29.

founder added lead to the mixed mass which he wanted to refine.

Lead, when reduced to an earth, by being burned in the open air, may, in a stronger degree of heat, be converted into a yellowish glass,\*

which

\* Other metallic substances yield coloured glasses, either when vitrified alone, or in conjunction with pure glass. In enamel and china painting they prepare rose red and purple colours from gold; scarlet reds from iron, or vitriols that partake of it; greens from copper; blues from cobalt; blacks from magnefia, zafter, and scales of iron; yellows from filver antimony, Naples yellow, and crocus martis; white from tin. The same substance yields different colours, according to the degree of heat to which it is exposed; thus, the green colour of common glass bottles, which proceeds from the iron contained in the fand and vegetable ashes from which the glass is made, is changed into a blue by a stronger degree of heat.

which has the property of greatly contributing to the eafy vitrification of all earthy substances; hence, when gold or silver are mixed with iron, copper, or tin, it is usual to add to the mixed mass a quantity of lead, in order to accelerate the purification; for the lead will be converted into glass, and this glass will vitrify all the extraneous substances with which the gold or silver are polluted, without exerting the least action upon the precious metals themselves.

I do not know upon what grounds one of the most distinguished chemists of the age has afferted, "that the refining of gold and silver merely by the action of the fire was the only method anciently known;" †

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<sup>†</sup> Chem. Dict. by M. Macquer. artic... Refining.

and that the doing it by the addition of lead, is a discovery with which the ancients were unacquainted. Not to infift upon what has been quoted from Jeremiah; in Diodorus Siculus there is a very minute description of the manner of working some gold mines in the confines of Egypt and Arabia; this description was probably written on the spot when he visited that country, but the mode of operation feems to have been derived from a more early period; as the discovery of the mines is attributed by him to some of the most ancient Ægyptian kings; amongst other particularities, he takes notice of their melting the mineral in conjunction with a little tin, some small portion of falt, and a lump of lead.\* Strabo

<sup>\*</sup> Diod. Sic. Lib. III. p. 183 - 189.

Strabo quotes Polybius as speaking of a filver ore, which, after being five times washed, was melted with lead, and became pure filver. Unfortunately this part of the works of Polybius is loft, or we might have had a more circumstantial knowledge of the processes by which the ancients extracted filver from its ores, as Strabo fays, that he omitted Polybius' account of this matter, because of its prolixity. † Pliny probably has an allusion to the use of lead in refining filver, when he fays, that a filver ore in the form of an earth could not be melted except in conjunction with lead or the ore of lead. \* A more diligent search into the writings of the ancients, would, doubtless.

<sup>+</sup> Strab. Geo. Lib. II. p. 221.

<sup>\*</sup> Plin. Hift. Nat. Lib. XXXIII. C. VI.

less, furnish more authorities upon the point, but these may be sufficient to induce us to believe, that they were not unacquainted with the use of lead in resining gold and silver. — But to return to the manner of extracting silver from lead.

The veffel in which the workmen melt the mass of silver and lead is of a shallow form, that a large surface of the melted mass may be exposed to the air, it is made usually of four measures of the ashes of calcined bones, and of one measure of unwashed fern ashes, and is called a test.\* This vessel is very porous,

but

<sup>\*</sup> Tests are sometimes made of clay and other materials, and metallurgic writers often order the wood ashes to be washed, lest the alkaline salts which they contain should tend to vitrify the test; but a very good referen

but not so much as to imbibe the metal, whilst it continues in the form of a metal; but as the earth, into which the lead is foon reduced by the action of the fire, becomes melted, the test imbibes a portion of it in that liquid state, the other portion is driven off (as cream is blown off from milk) from the furface of the melted mass, by the blast of a bellows. The liquid, half vitrified, earth of lead, which is thus driven off, concretes into hard masses of a scaly texture, and is called in that state litharge, or filver stone, from the manner of its being produced, or from an idle notion of its containing

finer at Holywell informed me, that he always used the ashes without washing them, as the vessel became thereby less apt to crumble into pieces.

taining much filver. The litharge which is first formed is whitish, that which experiences a greater degree of heat is red; the colour of the litharge is also influenced by that of the other metals, which may chance to be mixed with the mass of lead and filver. When the furface of the melted mass becomes white, and throws up no more litharge, the operation is finished; but as the remaining filver is not quite pure, fince it contains a small portion of lead, from which the degree of heat requisite for melting the mixed mass. cannot readily free it, it is taken to a refining furnace, and rendered quite pure, at least from lead, by cupellation. This process consists in melting the filver obtained from the first operation, in a vessel made of the fame

fame materials as the test, and which, from its resemblance to a wide mouthed cup, has been called a cupel. The cupel being exposed to a stronger heat than the test, the lead which had escaped the action of the fire on the test, is now driven out from the filver, and being converted into litharge, is absorbed by the cupel, and by this means the filver is purified from every metal except gold; for it is not necessary, on this occafion, to remark, that a minute portion of copper, when there happens to be any in a mass of silver and lead, probably escapes the action of the fire in cupelling gold or filver.

There are feveral fmelting houses at *Holywell* in *Flintshire*, where filver is extracted from lead; Mr. *Pennant*\*

has

Tour through Wales.

has given the following account of the quantity of filver extracted at one of the largest of these houses in the course of fix years.

1.	Ounces.					Ounces.		
Year	1754	on	12160		Year	1774	00	5693 .
	1755	-	1276			1775	-	6704
	1756	-	7341			1776	-	4347

The filver obtained from lead at Holywell, is chiefly fold to the manufacturers at Birmingham and Sheffield. Much filver is also extracted from lead in Northumberland.

At Holywell they usually work off three tons of lead at one operation, the quantity of filver which they procure, is variable according to the richness of the lead; a few years ago they were refining lead from an ore found in the Isle of Man, and it gave them about 60 ounces at every opera-

operation, or 20 ounces in a ton of the lead. The litharge ordinarily obtained from three tons of lead amounts to 58 hundred weight; this litharge may either be changed into red lead by calcination, or it may be reduced into lead again by being fluxed with charcoal, or any other matter containing the inflammable principle; \* but when it is reduced they seldom obtain more than 52 hundred weight of lead, † so that by

ex-

<sup>\*</sup> Lead from litharge is, generally speaking, worth five shillings a ton more than ore lead, as the plumbers esteem it softer and sitter for making sheet lead; yet the litharge lead from the ore of the Isle of Man here mentioned, was found quite unsit for making sheet lead, on account, probably, of the ore having held other metals besides silver and lead.

<sup>+</sup> In the foreign works they estimate the loss of weight, which the litharge sustains in being

extracting the filver, there is a loss of eight hundred weight in three tons of lead. It has been faid that the Dutch can extract the filver from three tons of lead, and not lose above fix hundred weight \* upon converting the litharge into lead, and that this superior skill, aided, probably, by their superior industry, enabled them to purchase our lead, and to extract the filver from fuch as could not be refined here with advantage: I have been informed, however, by an experienced refiner in Derbyshire, that he could extract the filver without losing quite so much as six hundred

being reduced into lead, at a fixth part of the weight of the litharge, or  $9\frac{2}{3}$  hundred weight from 58 hundred weight of litharge. Estais des Mines, Tom. II. p. 401.

<sup>\*</sup> Webster's Metal. p. 233.

dred weight in three tons of lead; I make no question that the loss depends, in some measure, on the quality of the lead. It has been remarked before, that lead, which does not contain nine ounces of filver in a ton, is not thought worth the refining; the smallest quantity which can be extracted with profit, must depend much upon the price of lead, all expences attending the feveral processes being the same. For eight hundred weight of lead, which may be affumed at a medium as the loss fustained during the operations of refining and reducing, is worth 6 f. when lead is at 15 f, a ton, and it is worth only 4 f. 16s. when it is at 12 f. a ton. The value of 27 ounces. of filver, which we suppose to be the quantity separable from three tons

of lead, is 7 f. 10s. 9 d. at 5 s. 7 d. an ounce; hence, the difference between the value of the filver obtained, and that of the lead loft, would, when lead is at 15 £. a ton, be 1 f. 10 s. 9 d. and when lead is as low as 12 f. a ton, it would amount to 2 f. 14s. 9d. In the time of Sir John Pettus, the usual allowance for waste in refining and reducing of lead, was three hundred weight in a ton, or nine hundred weight in three tons, and the lead was valued at 12 f. a ton, + so that lead has altered very little in its price in the course of above one hundred years.

Silver is here valued at 5s. 7d. an ounce; this requires some explanation. A pound of standard filver in England, consists of 11 ounces

<sup>+</sup> Fodinæ Reg. p. 10.]

ounces and 2 pennyweights of fine filver, and of 18 pennyweights of copper; in other words, every mais of standard filver confisting of 40 parts by weight, is composed of 37 parts of fine filver, and of 3 parts of copper; the copper is called the alloy. All nations use some alloy both in their gold and filver; partly with a view of rendering these metals harder, and partly because it would require much labour and expence to free them wholly from that small portion of copper, which, in their ordinary state, as fluxed from their ores, they are generally found to contain. A pound of standard filver is coined into 62 shillings, hence the Mint price of an ounce of standard filver would be a twelfth part of 62 shillings, or 5s. 2d. From hence

it might be shewn, by the rule of proportion, that the market price of an ounce of fine filver, which contains no copper, will be 5s. 7d. at the least. The market price of silver bullion does not wholly depend on the mint price, it can never be lower than that, but, from the operation of various causes, it may exceed it. + - Standard gold with us consists of 11 parts of fine gold, and of 1 part of copper, or of a mixture of filver and copper; and a pound or 12 ounces of standard gold, is coined into 442 guineas; hence the price of an ounce of standard gold is 3 f. 17 s.  $10^{\frac{1}{2}}d$ . and the price of an ounce of fine gold is 4 f. 4s. 111 d. Foreign gold trinkets stain the hands more, and have a more coppery look

<sup>+</sup> Essay on Money and Coins, p. 2. & 55.

look than English ones; and in fact they are made of gold which is alloyed with a much greater proportion of copper, than the standard gold of England; yet when an enamel is to be fixed on gold, one of the most experienced of the foreign enamellers, † recommends the use of gold, which has the same alloy as the English standard gold, or two parts alloy and twenty-two parts of sine gold.

Copper communicates a smell both to gold and silver. The Roman specula, which they used as looking glasses, in Pliny's time were commonly made of silver, but the silver was alloyed with much copper; for we find a cunning waiting maid in Plautus advising her mistress to wipe her fingers

<sup>†</sup> M. de Montamy, Traite des Coleurs.

fingers after having handled a speculum, lest her paramour from the the smell of her singers should suspect her of having received silver from some other lover.

Ut speculum tenuisti, metuo ne oleant argentum manus.

Ne usque argentum te accepisse suspicetur Philolacles.\*

Plaut. Most. Act. I.

ESSAY



## ESSAY X.

## Of Red and White Lead.

If the reader does not know what minium or red lead is, I would wish him to fend for a few ounces of it to his painter or apothecary. — Supposing him to have a parcel of red lead before his eyes, the first thing which will strike him is its vivid colour verging a little towards orange; if he crumbles it between vol. III. Y his

his fingers, he will find it to be an almost impalpable powder; if he poizes it in his hand, he will perceive it to be much heavier than either brick dust or red ochre, with which substances it is sometimes adulterated; if he compares it with a piece of lead, he will be associated how it can be either produced from lead, or be capable of being, by a very slight operation, reduced into lead again.

It has been mentioned in the preceding Essay, that red lead is made from litharge at Holywell: this red lead which is made from litharge is not, perhaps, in all its properties of quite the same kind with that which is made directly from lead; at least I have been informed, that the makers of slint glass, who use much red lead

lead in the composition of that glass, are of opinion, that the litharge red lead does not flux so well as that which is made from the direct calcination of lead, as is practised in *Derbyshire*. There are in that county nine red lead mills or furnaces, all of which are much upon the same construction.

The furnace is very like a baker's oven, its vaulted roof is not at a great distance from the bottom or floor, on each side of the furnace there are two party walls, rising from the floor of the furnace, but not reaching to the roof; into the intervals between these walls and the sides of the furnace the pit coal is put, the flame of which being drawn over the party walls and striking upon the roof, is from thence reslected

Y 2 down

down upon the lead, which is placed in a cavity at the bottom, by which means the lead is foon melted. The furface of melted lead, when exposed to the open air, instantly becomes covered with a dufky pellicle; and this pellicle being removed another is formed, and thus by removing the pellicle, as fast as it forms, the greatest part of the lead is changed into a yellowish green powder. This yellowish powder is then ground very fine in a mill, and being washed, in order to separate it from such parts of the lead as are still in their metallic state, it becomes of an uniform yellow colour, and, when it is dried to a proper confistency, it is thrown back again into the furnace, and being constantly stirred, so that all its parts may be exposed to the action action of the flame of the pit coal, in about 48 hours it becomes red lead, and is taken out for use.

The colour of the red lead admits fome variety, which is occasioned by the different degrees of heat. If the heat is too small, instead of red it is yellow or orange coloured; if it is too great the red colour is changed into a dirty white, between these two extremes it is subject to some diversity of shades of red, which cannot well be noticed or described, except by those who are engaged in the making of it.

It has been afferted, that the reverberation of the flame and fmoke upon the furface of the lead, is not a necessary circumstance in giving it a red colour, \* but that it will acquire

<sup>\*</sup> Instit. de Chym. par M. Demachy. p.522.

quire this colour by a long calcination without coming in contact with the flame. The truth of this affertion I think may be doubted. I have more than once calcined lead for above 60 hours, without suffering the flame of the fire to touch it during any part of the process, but by this method I could never obtain any thing better than a dirty red, resembling the red of brickdust, which is very different from the colour of red lead; and even this dirty red was changed into a yellow colour, by augmenting the degree of heat with which the lead had been calcined. The method of making red lead is very well understood in England and Holland, but not in France; and the French workmen are

of opinion, that it cannot be made by the flame of wood fires. \*

During the making of red lead, part of it is volatilized, there rifes up from it a vapour, which attaches itself to the roof of the furnace, and forms folid lumps. These lumps are of a yellowish white colour mixed with pale green and some reddish streaks, wherein are frequently small red crystals, resembling such as may be artificially formed by fubliming fulphur and arfenic together. The workmen call the whole of what is separated from the lead in the form of smoke, sulphur: when this sublimed matter is detatched from the roof of the furnace, the red parts

are

<sup>\*</sup> Mem. de l'Acad. des Scien. 1770. – Elemens de Mineral. par M. Sage. Vol. II. p. 248.

are converted, by a subsequent procefs, into red lead; and the yellow ones are fent to the smelting furnaces, to be run down again into lead. The quantity of this fublimate amounts to about five hundred weight in making one hundred tons of red lead. The proportion here affigned is not wholly to be relied on, fince the Imoke arising from the lead, forms itself into larger masses and in less time, when it is not constantly swept from the roof of the furnace than when it is, and the workmen endeavour to keep the roof as free from it as they can, because a small portion of it injures the colour of a large quantity of the red lead with which it happens to be mixed.

A ton or twenty hundred weight

of lead generally gives twenty-twohundred weight of red lead, notwithstanding the loss of substance which the lead evidently fultains from the copious smoke which arises from it during the operation. Some authors tell us, that the increase in the weight of the red lead is double what I have here mentioned: thus, Orschall speaking of the red lead made at Nuremberg, affures us, that 100 pounds of lead yield 120 pounds, and fometimes even more, of red lead. \* It is not impossible that, according to the different manners of conducting the process, there may be a difference in the quantity of weight which the red lead acquires: I had my information from fome of the most experi-

<sup>\*</sup> Orsch. Metal. French Trans. p. 100. — M. Sage's Mine. Vol. II. p. 384.

experienced makers of red lead in Derbyshire. There have been great disputes amongst philosophers, to what principle this increase of weight should be ascribed; some have attributed it to what they call the matter of fire; others are upon good grounds convinced, that it is owing to the absorption of the air itself, or of fome of the principles of which the air consists. This hypothesis concerning the fixation of air during the calcination of metals, is faid to have been first advanced by John Rey a French physician in 1630; Dr. Hales was partly of the same opinion; \* and Dr. Pemberton very expressly affirms, that calcined metals receive their increase of weight from the air, which "by acting on the inflammable

<sup>\*</sup> Veget. Stat.

ble substance, either in metals or other bodies, expels it from them, and unites itself (in part at least) to the remains of the body".\* The ingenious labours of Dr. Priestley and of M. Lavoisier have confirmed the conjectures and experiments of former philosophers, for they have clearly proved two points — first, that a large portion of air may be separated from red lead, by reducing it to the ftate of a metal; - and fecondly, that a large portion of air is abforbed by lead during the calcination, by which it is reduced to the state of red lead. +

During the calcination of lead, it is certain, from what has been faid,

<sup>\*</sup> Pember. Chem. p. 245.

<sup>†</sup> Priestley's Exper. and Lavoisier's Essays, translated by Henry.

that much of its substance is disperied into the air; this substance may indeed be feen afcending as a smoke from the furface of the lead, if the heat be so great as to make it boil; and in a less degree of heat, the vapour which afcends from it, may be: rendered visible, by holding over it a wet iron ladle to condense it. But at the same time, that the lead loses considerably of its weight by the volatilization of part of its substance, it receives such an accession of new matter from the air, as renders the weight of the part which remains, much greater than that of the whole lead which was exposed to calcination. This accession of aërial matter may be driven off from red lead, by restoring to it the inflammable principle which was confumed during the

the calcination; but after this extraneous matter is driven off, by reducing the lead, we ought not to expect that the lead, which is thus brought back to its former state, should weigh as much as it did before it was calcined; because that part of it which was volatilized and dispersed into the air cannot be recovered. And in fact, it was observed in the last Essay, that three tons of lead, when converted by calcination into litharge, had loft two hundred weight; this quantity, and, probably much more than this, had been volatilized and lost, for the remaining fifty-eight hundred weight confisted partly of the earth of lead, and partly of the air which had been fixed in it during the calcination; and hence, when it was reduced, it did not give above

above fifty-two hundred weight. In calcining then, and reducing fixty hundred weight of lead, there is a loss of eight hundred weight: a great part of this loss is rightly referred to the volatilization of the lead, but a part also may justly enough be referred to the scoria which remains after the reduction of the litharge into lead, that operation being feldom performed so accurately as not to leave fome part of the litharge unreduced. I have here spoken of the loss of weight, sustained during the reduction of litharge, as if it was the fame as that which red lead fustains; there, probably, may be fome difference between them, but the general inference is the same; and I have been informed moreover, that there is neither increase nor decrease

crease in weight, in converting litharge into red lead.\*

In making red lead in Derbyshire, the workmen mix one hundred weight of stag lead with about eighteen hundred weight of ore lead; and they are persuaded that this stag lead has a great effect, in accelerating the conversion of the other lead into an earth. Tin, when mixed with lead, very much promotes its calcination; and the stag lead has this property

\* This observation does not accord with that of the author of the Familiar Discourse concerning Mines. p. 34. — "20 hundred weight of this litharge will produce 22 hundred weight of red lead." Another author informs us that 20 pounds of lead will by a long calcination give 25 pounds of ashes, and that these 25 pounds of ashes will when reduced, give 19 pounds of lead. Lemery Cours de Chym. p. 145.

property in common with a mixture of tin and lead, that it does not, when melted, exhibit any colours on its furface: may not its properties, by which it is distinguishable from ore lead, arise from its containing zinc or tin? We are too apt, I think, to look upon the ores of lead as containing only one metal; since we are certain that they all contain two, namely, lead and silver; and it may be, that they contain other metallic substances, particularly zinc and tin.

In converting a ton of lead into red lead, the workmen observe, that towards the end of the operation, a few pounds of lead are always found to remain, which cannot be changed into red lead, with the same facility with which ordinary lead is changed. When I was first inform-

ed of this circumstance, I considered it in the following manner. - Derbyshire lead, though it does not contain filver enough to render the extraction of it profitable, yet it generally contains five or fix ounces in a ton: filver is not capable of being converted into an earth by the action of air and fire, when therefore a ton of lead is converted, as to its greatest part, into red lead, why may not the fix ounces of filver contained in that lead, be left unaltered? and may not the superior difficulty of reducing the last portion of the lead into red lead, proceed from hence, that it is much more impregnated with filver, than ordinary lead is? Under the influence of this conjecture, I procured from Derbyshire, some of the lead which remained VOL. III. Z ununcalcined in the making of red lead, and I assayed it for silver; but it did not contain more silver, than many specimens of ore lead contained.

It has been remarked, more than once, that red lead may be reduced into lead, by being melted with rofin, tallow, charcoal, or any substance containing the inflammable principle. The proof of this is very easy; a few grains of red lead being scattered on a piece of red hot charcoal, will be changed into globules of lead; or if the reader burns a common red wafer in the flame of a candle, holding a piece of white paper under it; he will fee many red hot globules falling upon the paper, and thefe globules he will find to be lead: this lead proceeds from the red lead with which

which ordinary wafers are coloured, being reduced into the state of a metal, by uniting itself with the inflammable principle. The best waters are coloured with vermillion — powdered einnabar.†

Having been disappointed in the expectation of finding a large proportion of silver, in the small residue of lead remaining after the conversion of ordinary lead into red lead; and being unwilling to give up the notion, I was desirous of convincing myself that I had not been guilty of any mistake in the assay that I had made, by trying whether red lead itself did not contain silver; for if red lead contained silver, I saw no reason

to

<sup>+</sup> Cinnabar is an ore of quickfilver; it is composed of quickfilver and sulphur; generally of 7 parts of quickfilver to 1 of sulphur.

to be furprised at the residue, before mentioned, not containing more than I found it to do. I therefore reduced a quantity of red lead into the state of a metal, by melting it with rosin; this reduced lead was carefully affayed more than once, and it always afforded a portion of filver. Hence we may conclude, that the filver contained in lead, though it be not subject to calcination during the process of making red lead, is nevertheless mixed with the calcined lead in fuch a comminuted state, as to escape our senses; the filver, probably, is still in the form of silver, but its particles are so indefinitely fine, that they cannot be distinguished in the mass of red lead, which contains them.

The method of making slag lead has

has been described before; I affayed this kind of lead feveral times, and I sometimes obtained from it a globule of filver, at other times there was no appearance of filver. This difference in the result of the assays, is not to be attributed to any difference in the quality of the flag lead which was affayed, for all the pieces which I tried were cut from the fame lump, but to the different degrees of heat used in the operation; when the fire was too flrong, the filver, I conceive, was volatilized. Silver I know is looked upon as a fixed metal, and not capable of being volatilized; and the loss of filver when the fire is too strong, has been attributed to its being not volatilized, but absorbed by the cupel; I have no objection to this account;

but

but that the volatilization of filver on the cupel is no unwarranted conjecture, appears from hence, that in the last process of refining lead for filver at Holywell, so much of the silver is carried into the chimney of the furnace, that they have procured a silver cup from melting the sweepings.

A great quantity of lead is annually imported in the tea boxes from China, a Congo box contains about 10 pounds, and an Hyson box about 4 pounds of lead; I have frequently assayed this lead, and always found that it contained silver, but not in quantity sufficient to quit the expence of extracting it.

Pure lead is heavier than pure filver, and the purer the lead the greater is its weight; I calculated the weight

## ( 359 )

weight of a cubic foot of five different forts of lead:

Weight of a cubic foot of

Avoir.oz.
Lead from the reduction of red lead 11460
Lead uncalcined in making red lead 11331
Lead smelted from an ore - - 11262
Lead from the slag of a cupola furn. 11212

Léad from a tea box - - - - 11176

The experiments from which I formed this table, were repeated at different times, and the mean of several trials in the respective sorts is expressed. A cubic foot of sine silver weighs 11091 ounces.\*

The following affays of the feveral leads here mentioned, were made by an experienced affayer in London; they are very little different from those

<sup>·</sup> Cotes.

I was defirous that the reader might rely upon the authority of a person versed in the particular business of assaying, rather than upon mine.

## Fine filver in a pound of

	Title miles and a pound of	
	· Gi	cains.
Lead	from the reduction of red lead	1 7
Lead	uncalcined in making red lead	I 1/2
Lead	fmelted from an ore	13/4
I.ead	from the flag of a cupola furn.	134
Lead	from a tea box	13/4

From comparing the two tables together, we see that the heaviest lead contains the least silver: I do not think, that persons interested in knowing the quantity of silver contained in any particular specimen of lead, should rest satisfied with assaying so small a portion as a pound, especially if no notice is taken of

any weight less than one fourth of a grain.

White lead or ceruse, is lead corroded by vinegar. Thin plates of lead are rolled up in a spiral form, and placed in earthen pots containing vinegar; these pots being ranged on proper stages, and their mouths being covered in fuch a manner, as to permit the vapour of the vinegar to escape, and at the same time to prevent any impurity from falling into them, a quantity of horse dung is thrown in amongst them; by the heat of which, as it grows putrid, the vinegar is raised in vapour, and this vapour attaching itself to both fides of every spiral of the lead, which is so placed as not to touch the vinegar, it corrodes the lead into white scales, which being beat off from

from the plates, washed and ground in a mill, constitute the white lead of the shops, excepting that this is generally, even before it gets into the hands of the painters, adulterated with chalk. Ceruse was formerly made by the vapour of putrid urine instead of vinegar. The time when this preparation of lead was first discovered is wholly uncertain; Dioscorides speaks of its being made in great perfection at Rhodes, Corinth, and Lacedemon, and of an inferior fort of it at Puteoli; ‡ and Pliny describes two ways of conducting the operation, both of which are now in use.\*

The Roman ladies were well acquainted with the use of ceruse as a cosmetic: Plautus introduces a wait-

ing

<sup>‡</sup> Diof. Lib. V. C. 103.

<sup>\*</sup> Lib. XXXIV. S. 54.

ing woman refusing to give her miftress either ceruse or rouge, because,
forsooth, in the true spirit of a flattering Abigail, she thought her quite
handsome enough without them.\*
I suppose the Christian ladies in the
days of St. Jerome, were given to this
pagan custom, for the venerable father inveighs very forcibly against
the

\* — non do, scita es tu quidem,

Nova pictura interpolare vis opus lepidissimum,

Non istanc ætatem oportet pigmentum ullum attingere,

Neque cerusam, neque melinum, neque aliam ullam offuciam.

Plaut. Most. Act. I.

Quid faciat in facie Christianæ purpurissus et cerusa, quorum alterum ruborem genarum, labiorumque mentitur, alterum candorem oris et colli, ignis juvenum, fomenta libidinum, impudicæ mentis judicia. Hieron. ad Fuscum.

the use of rouge for the lips and cheeks, and of ceruse for the face and neck, as incentives to luft, and indications of unchaste desires. Without prefuming to explore the arcana of a lady's toilet, or to reveal the arts by which my fair countrywomen endeavour to improve charms, naturally irrefiftible, I would add to to the admonition of St. Jerome, a caution more likely, in these degenerate times, to be attended to the certain ruin of the complexion, to fay nothing of more ferious maladies, which must ever attend the constant application of this drug. Nor is the magistery of bismuth or Spanish white, as it is called, much less pernicious than ceruse, notwithstanding its being in such repute in London, that the chemists can hardly

prepare it fast enough to supply the demand for it.\* But if, as is most probable, they will neglect this caution, I warn them, however, to forbear the use of such washes at Harrowgate, Moffat, and other places of the same kind, lest they should be in the state of the unlucky fair one, whose face, neck, and arms were fuddenly despoiled of all their beauties, and changed quite black by a fulphureous water. Indeed, all phlogistic vapours, and even the sun itfelf tends to give both the magistery of bismuth, and ceruse, a yellow colour: this observation may explain a line in

<sup>\*</sup> The magistery of bismuth is made by dissolving that semimetal in aqua fortis, and precipitating the dissolved bismuth from the acid, by water.

in Martial, where a cerused lady is faid to fear the sun. \*

Other fluids, besides the vapour of vinegar, corrode lead into a kind of ceruse. When plumbers strip the roofs of churches, or other buildings covered with lead, which has lain undifturbed for many years, they usually find that fide of the lead which is contiguous to the boards, covered with a white pellicle, as thick fometimes as an half crown: this pellicle is corroded lead, and is as useful for painting, and other purposes, as the best white lead. The lead on the fouth fide of any building is found to abound most with this

Mar. Ep. Lib. II. E. XLI.

<sup>\* —</sup> cretata timet Fabulla, nimbum, Cerusata timet Sabella, solem.

this white crust; that on the north fide having very little, or none at all of it. It is believed also, that lead which lies on deal boards, is not fo apt to be covered with this white incrustation, as that which lies upon oak; if there be any truth in this obfervation, it may, perhaps, be explained from hence, that oak contains a much stronger acid than deal, and this strong acid being distilled, as it were, by the heat of the fun in fummer, attaches itself to the lead and corrodes it: or this corrosion may be the effect of the fun and air, which, by their constant action, calcine or corrode the lead; and this calcined lead not being washed off by the rain, may, in the course of a great many years, form the crust here spoken of. It might be worth while

while, in a philosophical view, to examine more minutely than has been done, the difference between old lead which has loft fome of its parts by long exposure to the air, and new lead. The plumbers have affured me that if a pig of old lead, and an equal pig of new lead, be put together into the same iron pot, and exposed to the same degree of heat, the new lead will be melted much sooner than the old lead. Another difference betwixt them, respects the quickness with which they may be reduced to a calx, the new lead being observed to calcine much faster than the old.

Neither ceruse, nor litharge, nor minium, have any taste, but any of these substances being boiled in distilled vinegar, which has an acid taste,

tafte, will be diffolved in it; and the folution being crystallized will give one of the sweetest substances in nature, called Saccharum Saturni, or sugar of lead. It is this property which lead has of acquiring a fweet tafte by folution in an acid, that has rendered it so serviceable to those wine merchants who, respecting their own profit more than the lives of their customers, have not scrupled to attempt recovering wines, which had turned four, by putting into them large quantities of ceruse or litharge. I believe this adulteration is punished with death in some parts of Germany; and it is to be wished that it met with that punishment every where. In 1750 the farmers general in France being aftonished at the great quantities de vin gaté which VOL. III. Aa were

were brought into Paris, in order to be made into vinegar, redoubled their researches to find out the cause of the great increase in that article; for near thirty thousand hogsheads had been annually brought in for a few years preceding the year 1750, whereas the quantity annually brought in forty years before, did not exceed 1200 hogsheads. They discovered, that feveral wine merchants, affuming the name of vinegar merchants, bought these sour wines (which were still rendered more four by the custom of pouring into each hogshead fix pints of vinegar before it was fold,) and afterwards, by means of litharge, rendered them potable, and fold them as genuine wines. \*

Our

<sup>\*</sup> Exam. Chy. de Differ. Subs. par M. Sage. p. 157.

Our English vintners, there is reafon to fear, are not less scrupulous in the use of this poison than the French wine merchants; for it not only corrects the acidity of sourwines, but it gives a richness to meagre ones, and by this property the temptation to use it is much increased.

The reader may foon furnish himself with the means of detecting lead
when dissolved in wine. Let him
boil together, in a pint of water, an
ounce of quicklime and half an
ounce of flowers of brimstone, and
when the liquor which will be of a
yellow colour is cold, let him pour
it into a bottle, and corking it up,
reserve it for use. A few drops of
this liquor, being let fall into a glass
of wine or cyder containing lead,
A a 2 will

will change the whole into a colour more or less brown, according to the quantity of lead which it contains; if the wine be wholly free from lead, it will be rendered turbid by the liquor, but the colour will be rather a dirty white than a blackish brown.

Van Helmont \* was of opinion, that Paracelsus made no vain boast, in saying that he could cure two hundred diseases by preparations of lead; but he does not tell us of the many hundred persons he, probably, sent to their graves by his attempt. But it is beyond my ability, and falls not within my design, to discuss either the salubrious or poisonous qualities of lead; especially as the labours

<sup>\*</sup> Adeo ut non frustra Paracelsus glorietur folo plumbo forte ducentas morborum classes superare posse. Helm. Op. p. 561.

labours of Sir G. Baker † and Dr. Percival ‡ have fo fully illustrated that subject.

Having accidentally heard, during the printing of this volume, that Dr. Priestley had discovered a method of reducing red lead to its metallic form, by melting it, in contact with inflammable air, by means of a burning glass, I was very desirous of having so remarkable a fact confirmed by other experiments. But being prevented by a bad state of health from venturing into an elaboratory myself, I communicated my wishes and ideas to an ingenious gentleman of this university, \* who has for some years been cultivating chemistry with

a pro-

<sup>†</sup> Med. Ess. ‡ Ess. on the Poison of Lead. \* Rev. Mr. Milner, A. M. Fellow of Queen's College.

a proper degree of enthusiasm, and he has fucceeded in reducing red lead by means of inflammable air in the following manner. To one end of a glass tube, into the middle of which some red lead had been put, an empty bladder was tied; to the other end a bladder full of inflammable air, obtained from a solution of iron in the acid of vitriol, was fastened very close: that part of the tube, in which the red lead was principally lodged, being heated almost red hot, by being held over a fmall crucible full of burning charcoal, the inflammable air was pressed out of the bladder; at its first passage through the tube the red lead became brown, as if it had been mixed with some oleaginous particles; and by pressing the bladders alternately for . a short

a short space of time, the red lead was reduced into small globules of lead; the quantity of inflammable air was sensibly diminished, a part of it having been absorbed by the red lead, when it became a metal.

Occasion was taken in another place to remark, that inflammable air, as a constituent part of combustible bodies, bore a great resemblance to phlogiston, \* and a doubt also has been expressed, whether the phlogiston of metallic substances be not an elastic inflammable sluid; this experiment, in which lead is reduced by absorbing inflammable air, tends very much to strengthen that hypothesis, and I doubt not we shall see reason to admit it without hesitation, when the subject has been more investigated;

<sup>\*</sup> Vol. Il. p. 331.

vestigated; at present I do not know whether it has been proved, that the whole of any definite quantity of inflammable air can be absorbed by a metallic earth; nor, if it cannot, what the nature of the remainder is: but the removal of these, and other doubts, will be best accomplished by the ability of him, to whom we owe the first suggestion, of the phlogiston of metallic substances being an inflammable air.

END OF VOL. III.













